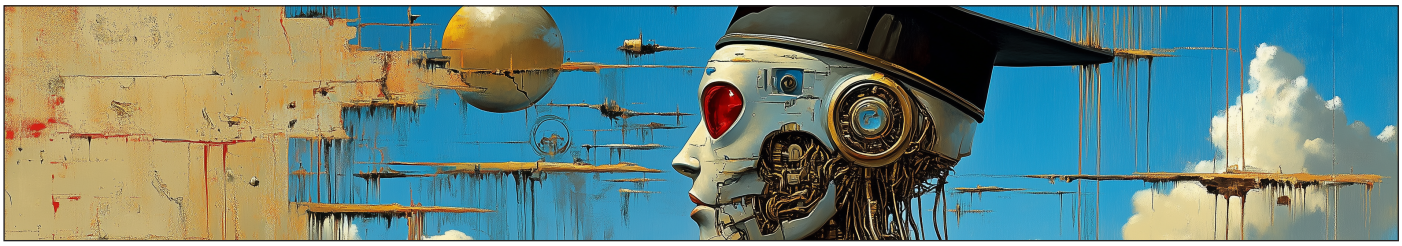
Studies in Technology Enhanced Learning

Journal homepage: **stel.pubpub.org**

Article type
Full paper, double-blind peer review.

Publication history
Received: 16 July 2024. Revised: 14 October 2024. Accepted: 14 October 2024. Online: 28 October 2024.

Cover image
Badly Disguised Bligh via flickr.



Special issue Generative AI and education | **More at** https://doi.org/10.21428/8c225f6e.0390b853

The effects of Generative Artificial Intelligence on Intelligent Tutoring Systems in higher education: A systematic review

Batzaya (Zack) Batsaikhan [1] and Ana-Paula Correia [2]

[1] College of Education and Human Ecology, The Ohio State University, Columbus, Ohio, United States of America

[2] Center on Education and Training for Employment, The Ohio State University, Columbus, Ohio, United States of America

Abstract

There is a lack of research regarding artificial intelligence (AI) applications in education settings, especially on whether generative AI can effectively advance intelligent tutoring and begin a new era of AI-powered effective tutors. The purpose of this systematic review was to thoroughly explore the evolution, potential applications, and challenges associated with AI-powered tutoring systems, formerly known as intelligent tutoring systems (ITSs), within science, technology, engineering, and mathematics (STEM) disciplines in higher education. The research identified five prominent themes regarding the evolution of ITSs in the last five years: 1) integration of AI; 2) personalized and adaptive learning; 3) learning analytics; 4) inclusion and equity; and 5) STEM disciplines. In particular, it was found that ITSs are one of the key applications of AI technologies in education. The studies reviewed indicate that emerging technologies, including virtual reality, augmented reality, robots/avatars, and voice assistants, will likely play crucial roles in the next generation of these systems. Additionally, emphasis was placed on online and remote learning, gamification, inclusion, and equity.

Keywords
intelligent tutoring systems; generative artificial intelligence; higher education; STEM disciplines

Citation
Batsaikhan, B. (Zack), & Correia, A.-P. (in press). The effects of Generative Artificial Intelligence on Intelligent Tutoring Systems in higher education: A systematic review. **Studies in Technology Enhanced Learning, 4**(1), 1-19.

https://doi.org/10.21428/8c225f6e.33570bb1

https://doi.org/10.21428/8c225f6e.33570bb1

In contrast, ethical issues are becoming a significant concern due to the enormous data usage of AI, specifically personal and other sensitive information. There is a general distrust toward AI technology, and ITSs are still new to many educators. Therefore, the systematic review evaluates how crucial it is to harness the potential of generative AI and ITSs responsibly. As we move forward, ensuring that ITSs complement, rather than replace, the essential role of human tutors is critical.

1. Introduction

Artificial Intelligence (AI) has recently become a popular topic in many areas of our daily lives. The quest to determine if machines can "think" has been around for at least six decades since the term was first coined by John McCarthy of the University of Massachusetts in 1956 (Manaware, 2020). However, it is safe to say that the introduction of GPT-1, short for Generative Pre-Trained Transformers, in June 2018 and the consequent public launch of ChatGPT in November 2022, both by OpenAI, have really been the turning points for AI development in the last few years. Such has contributed to the rapid advancement of generative AI. Generative AI pertains to technology capable of independently generating novel content, including images, audio, video, text, and code (Lv, 2023). The technology has potential applications in various industries, and proof of that is the recent 2024 Consumer Electronics Show (CES), the largest in the world, where every product on display, even a toothbrush, boasted some form of generative AI implementation (Collins & Lanxon, 2024). The trends emerging from CES are widely recognized to set the technology advancement tone for the upcoming years, and not surprisingly, education is following suit as the AI education market is predicted to surpass $20 billion by 2027 (Wadhwani, 2023). On top of that, Goldman Sachs (2023) estimates that investments in generative AI will reach $200 billion globally by 2025 and projects that AI adoption will accelerate in the second half of the decade, resulting in widespread usage.

1.1 Collaborative learning and Generative AI in higher education

Collaborative learning and human-to-human interactions will always be inseparable parts of the learning and teaching process. However, in an era defined by rapid technological advancements, it is essential to recognize the growing importance of generative AI in education. According to Government Technology (2023), 85 percent of the high school and college students "who completed study sessions with a human tutor as well as with ChatGPT found the generative AI method yielded better results" (p. 1). Generative AI has the potential to reshape the landscape of learning and teaching.

One of the most compelling features of generative AI is its ability to provide personalized learning experiences. Traditional learning environments often struggle to cater to the diverse needs of every student due to limited human resources and time constraints. However, AI-driven systems, like intelligent tutoring systems (ITSs), are designed to adapt to individual learning preferences and paces. By analyzing student data and learning patterns, these systems offer tailored guidance, feedback and support, allowing learners to progress at their own pace while addressing their specific strengths and weaknesses. College students may be able to maximize their productivity, focusing on areas that need improvement and achieving their academic goals more efficiently (Correia, 2023). On the topic of generative AI's impact on assessment in higher education, Smolansky et al. (2023) concluded that while educators favored adapted assessments that assume AI usage and promote critical thinking, students had mixed reactions, expressing concerns about losing creativity. This study highlights the need to engage both educators and students in reforming assessments to emphasize learning processes, higher-order thinking, and real-world applications.

In addition to enhancing student performance, generative AI holds promise for educators. By harnessing AI, teachers can manage workloads more effectively, use real-time data to inform teaching strategies, and enhance their ability to offer individualized support. AI systems can automate routine tasks, such as grading and feedback, freeing educators to focus on more meaningful interactions with students and reforming assessments, as mentioned earlier. This dual support—benefitting both students and teachers—reinforces the idea that AI, far from replacing human interaction, can augment it, creating more enriching and efficient educational experiences for all in higher education.

1.2 Intelligent Tutoring Systems

Before the public release of ChatGPT in November 2022, a large language model-based generative AI chatbot developed by OpenAI, personalized learning experiences were heavily reliant on ITSs. ITSs are computer programs or systems that give students personalized instruction and feedback (Psotka et al., 1988). This could mean offering more practice problems in areas where students struggle or advancing more quickly when they excel. ITSs come in various types, each offering unique features and benefits and catering to different learning needs and domains. They

range from complex ITSs designed for training on the functioning and operation of industrial equipment to educational software that can be installed on a computer such as LabTutor (Crompton & Burke, 2023). Recently, these systems have taken the form of advanced AI chatbots and virtual assistants incorporating generative AI and other emerging technologies (Gupta & Chen, 2022). While schools and universities are often now equipped with digital devices and learning management systems, replacing textbooks with eBooks, physical classes with Zoom, and so on, it can be argued that the fundamental nature, principles, administrative practices, and traditions remain unchanged beneath the digital innovation surface (Selwyn, 2021). The literature review indicates that the field of ITSs, even though it was first introduced in the 1980s, is still in its infancy stage, recently growing exponentially, and has high potential for learning and teaching. The development of ITSs, even though it employed various AI and machine learning techniques to adapt to individual learners, also followed in these footsteps, as the instructions and rules had to be programmed mostly by hand, making it a difficult and time-consuming endeavor. Now, combined with the capabilities of generative AI, teaching the computer how to teach provides new methods to rapidly build ITSs that can consistently improve the educational outcomes of students (Weitekamp et al., 2020).

1.3 The need for this systematic review

Science, Technology, Engineering, and Mathematics (STEM) are among the current research trends in ITSs (Guo et al., 2021). Initially, ITSs focused on teaching and learning at the individual level, providing personalized instruction and feedback to students (Zawacki-Richter et al., 2019). The early ITS models from the 1970s integrated student, teacher, domain, and diagnosis models to enhance the learning experience (Xu & Fan, 2022). However, more longitudinal studies and more research are needed on the effectiveness of these systems (Shi et al., 2022). More recent studies have explored the use of AI techniques in ITSs, such as artificial neural networks and decision trees, to predict student academic motivation and performance (Rosé et al., 2019). The application of data mining and big data analytics has transformed ITSs into intelligent analytics systems, focusing on adaptive guidance programs based on large datasets (Renz & Vladova, 2021). The evolution of ITSs has also led to pedagogical modifications, improving learning outcomes in redesigned tutoring systems. Overall, it is apparent that ITSs continue to evolve, with a growing emphasis on generative AI and personalized and adaptive learning. Therefore, there is a crucial need for a systematic literature review to investigate the evolution of ITSs with generative AI (2018-2023). Moreover, there is a need to identify what the next generation of these systems, unquestionably generative AI-powered, could look like in the years to come, as well as their possibilities and limitations. The articles used in this review are related to STEM and higher education, as outlined in the inclusion criteria following, and the review is about how ITSs are changing with generative AI in the context of higher education STEM disciplines.

AI-powered teaching will occur, and disruptions will inevitably happen, but “no technological advance has ever replaced teachers” (Grossman, 2023, p.1). The criticality of analyzing tutoring/teaching supported by ITSs is relevant in the current higher education landscape, particularly in STEM disciplines. Thus, the main questions that guided this review are:

1. How have intelligent tutoring systems evolved in the last five years (2018-2023)?
2. How effective are the current available AI-powered tutors?
3. What could the next generation of intelligent tutoring systems look like?
4. What are the opportunities and limitations of AI-powered tutors to complement the role of human tutors?

2. Methodology

This systematic literature review adhered to the widely used three-phase study review procedure outlined in the United States (U.S.) Department of Education’s Institute of Education Sciences, *What Works Clearinghouse Procedures and Standards Handbook, Version 5.0* (2022): (1) Screen studies for eligibility; (2) Review study findings; and (3) Synthesize and report results. We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure accuracy and quality in the identification and screening process.

2.1 Data sources and search strategies

We conducted an exhaustive search across all databases integrated into the EBSCOhost system to guarantee comprehensive inclusion of the current body of literature. Additionally, we utilized Semantic Scholar, an artificial intelligence-powered research database, for further exploration. The search queries used for both research databases were: (intelligent tutoring system) AND (generative AI OR artificial intelligence OR AI in education) AND (educational technology OR personalized learning OR STEM).

https://doi.org/10.21428/8c225f6e.33570bb1

Table 1. Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Publication date	From January 2018 to December 2023	Before 2018 and after 2023
Publication type	Peer-reviewed journal articles	Non-peer-reviewed journal articles, book chapters, reports, dissertations, conference proceedings, or blog posts
Research focus	Design, implementation, or analysis of Intelligent Tutoring Systems using generative AI. The application of artificial intelligence technology in education	Without design, implementation, or analysis of Intelligent Tutoring Systems using generative AI. Without the application of artificial intelligence technology in education
Context of study	Higher education. STEM disciplines	K-12 and other educational settings. Other disciplines
Language	English	Other languages

2.2 Inclusion and exclusion criteria

GPT-1 was introduced in June 2018, arguably the first true generative AI model (OpenAI, 2018). Since we were interested in the evolution of ITSs in the era of generative AI, this study specifically focused on articles published within the last five years (2018-2023) in order to dive into the most recent ITS advancements. Even though generative AI is an emerging technology that is still being actively developed and experimented with, we decided to use only peer-reviewed journal articles to ensure more reliable and valid results. Most relevant research was conducted within the realm of higher education, specifically the STEM disciplines. Thus, this study exclusively focused on these disciplines to maintain a manageable sample size. We ensured that the articles included in the final analysis of this study would satisfy all of the inclusion criteria outlined in Table 1.

2.3 Identification and screening process

After searching the databases, a total of 462 articles were found: 239 from EBSCOhost and 223 from Semantic Scholar. We removed 124 duplicates and screened the remaining articles by title and then the abstract. We identified articles that contained the search terms in their abstracts, yielding 258 potential articles. Next, after analyzing the full texts of these articles guided by the inclusion and exclusion criteria, only 28 articles were left. Full text was not available to retrieve for five articles, and 225 were excluded because they did not meet the inclusion criteria. Then, the full text of the remaining 28 articles was read, assessing their eligibility, and 22 articles were considered relevant for this review. As part of the reading process, we reviewed the references of the selected articles. We identified six more potential articles from the references, and three of them that met the inclusion criteria were added to the list. Such afforded a final selection of 25 articles for this systematic review. The process we used, based on PRISMA, is shown in Figure 1.

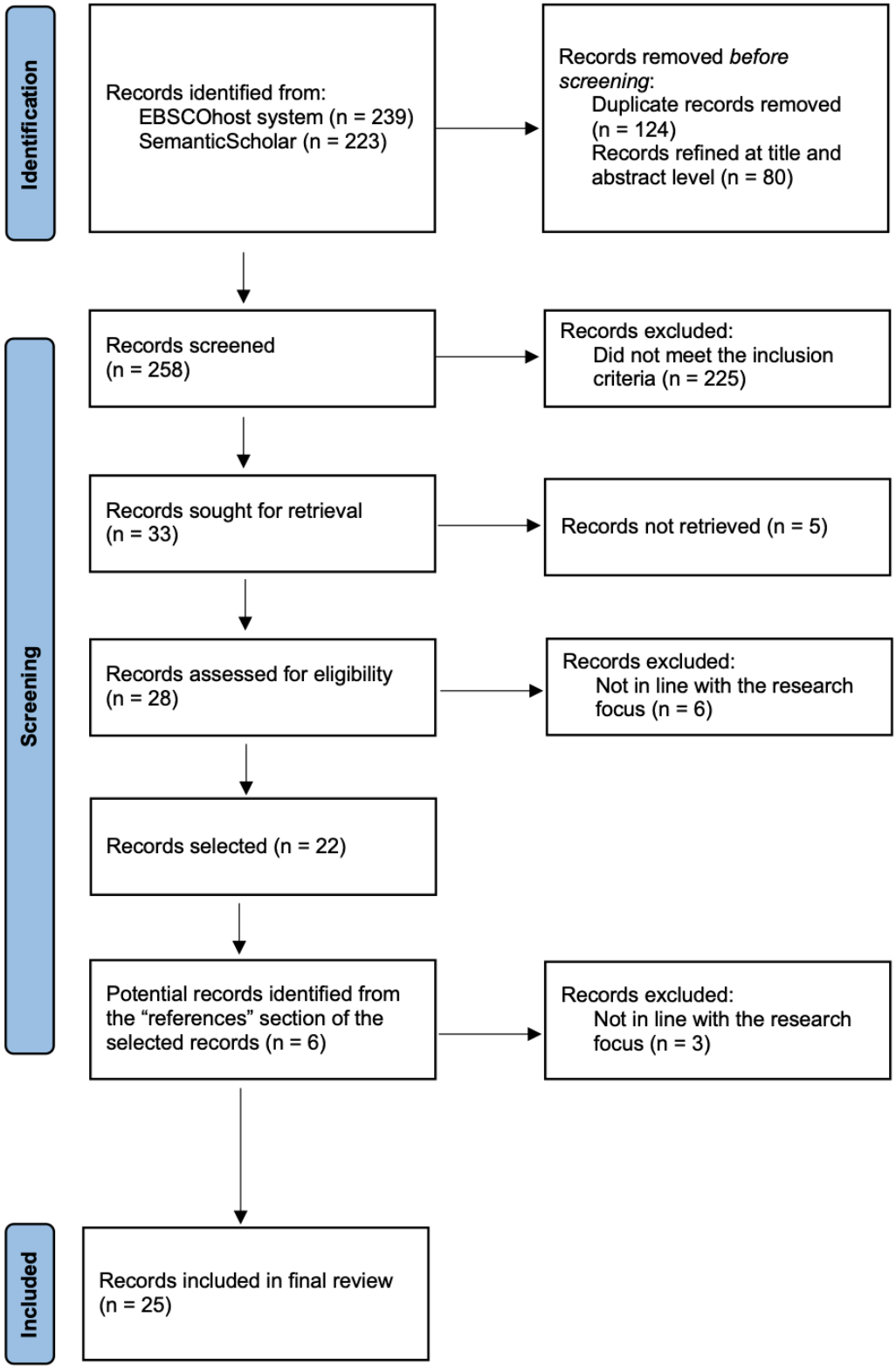
2.4 Data extraction and analysis

The data extraction and coding process was straightforward. This included publication information, article type, research methods, research foci, research results, applications of generative AI in education or ITSs using Generative AI, and emerging technologies used or proposed. Extracted data were used for content analysis to identify the emerging themes of research foci, research results, and future trends. We created a coding system using Microsoft Excel and a combination of AtlasTI software. The coding elements and their description are presented in Table 2.

3. Results

The 25 articles included in this systematic review, as indicated in Table 3, were published in 18 distinct academic journals between 2018 and 2023. It is worth noting that five articles, the highest number, were published in the *Sustainability* journal, which was an intriguing discovery because technology and education are not the primary focus of the journal.

Figure 1. PRISMA Flow diagram



https://doi.org/10.21428/8c225f6e.33570bb1

Table 2. Data extraction and coding elements

Element	Description
Publication information	Title, abstract, author(s), published date, journal name
Study type	Empirical study, literature review, and other
Research methods	Quantitative, qualitative, mixed method
Research foci	Themes will be identified through data extraction, open coding, and content analysis
Research results	
Applications of AI in education or ITSs using Generative AI	
Emerging technologies used or proposed	

Table 3. Articles selected for the systematic review

Year	Author	Title	Publication Title
2019	Alkhatlan and Kalita	Intelligent Tutoring Systems: A Comprehensive Historical Survey with Recent Developments	International Journal of Computer Applications
2019	du Boulay	Escape from the Skinner Box: The case for contemporary intelligent learning environments	British Journal of Educational Technology
2019	Rosé et al.	Explanatory Learner Models: Why Machine Learning (Alone) Is Not the Answer	British Journal of Educational Technology
2019	Zawacki-Richter et al.	Systematic review of research on artificial intelligence applications in higher education – where are the educators?	International Journal of Educational Technology in Higher Education
2020	Wang et al.	Participant or Spectator? Comprehending the Willingness of Faculty to Use Intelligent Tutoring Systems in the Artificial Intelligence Era	British Journal of Educational Technology
2021	Renz and Vladova	Reinvigorating the Discourse on Human-Centered Artificial Intelligence in Educational Technologies	Technology Innovation Management Review
2021	Xie et al.	Editorial Note: From Conventional AI to Modern AI in Education: Reexamining AI and Analytic Techniques for Teaching and Learning	Journal of Educational Technology & Society
2022	Chen et al.	Two Decades of Artificial Intelligence in Education: Contributors, Collaborations, Research Topics, Challenges, and Future Directions	Educational Technology & Society
2022	Chu et al.	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
2022	Gupta and Chen	Supporting Inclusive Learning Using Chatbots? A Chatbot-Led Interview Study	Journal of Information Systems Education
2022	Qian Cao et al.	Effect of Virtual Simulation Teaching System on Learning of Students Majoring in Engineering Technology	Journal of Engineering Science & Technology Review

Table 3. (cont.) Articles selected for the systematic review

Year	Author	Title	Publication Title
2022	Salas-Pilco et al.	Artificial Intelligence and New Technologies in Inclusive Education for Minority Students: A Systematic Review	Sustainability
2022	Shi et al.	Research Status, Hotspots, and Evolutionary Trends of Intelligent Education from the Perspective of Knowledge Graph	Sustainability
2022	Xu and Fan	The application of AI technologies in STEM education: a systematic review from 2011 to 2021	International Journal of STEM Education
2023	Abbas et al.	Role of Artificial Intelligence Tools in Enhancing Students' Educational Performance at Higher Levels	Journal of Artificial Intelligence, Machine Learning and Neural Network
2023	Alam and Mohanty	Educational technology: Exploring the convergence of technology and pedagogy through mobility, interactivity, AI, and learning tools	Cogent Engineering
2023	Bahroun et al.	Transforming Education: A Comprehensive Review of Generative Artificial Intelligence in Educational Settings through Bibliometric and Content Analysis	Sustainability
2023	Crompton and Burke	Artificial intelligence in higher education: the state of the field	International Journal of Educational Technology in Higher Education
2023	García-Martínez et al.	Analyzing the Impact of Artificial Intelligence and Computational Sciences on Student Performance: Systematic Review and Meta-analysis	Journal of New Approaches in Educational Research
2023	Ipek et al.	Educational Applications of the ChatGPT AI System: A Systematic Review Research	Educational Process: International Journal
2023	Jing et al.	Research Landscape of Adaptive Learning in Education: A Bibliometric Study on Research Publications from 2000 to 2022	Sustainability
2023	Kamalov et al.	New Era of Artificial Intelligence in Education: Towards a Sustainable Multifaceted Revolution	Sustainability
2023	Kumar et al.	Exploring the Transformative Role of Artificial Intelligence and Metaverse in Education: A Comprehensive Review	Metaverse Basic and Applied Research
2023	Nagaraj et al.	The Emerging Role of Artificial Intelligence in STEM Higher Education: A Critical Review	International Research Journal of Multidisciplinary Technovation
2023	Triplett	Artificial Intelligence in STEM Education	Cybersecurity and Innovative Technology Journal

https://doi.org/10.21428/8c225f6e.33570bb1

Moreover, three articles were published in the *British Journal of Education Technology*, while two were published in the *International Journal of Educational Technology in Higher Education*. The remaining articles were distributed across various journals, as illustrated in Table 4. Journals were related to educational technology, STEM education, emerging technologies, and sustainable education.

Table 4. Journals in which the reviewed articles were published

Publication Title	Frequency
Sustainability	5
British Journal of Educational Technology	3
International Journal of Educational Technology in Higher Education	2
Australasian Journal of Educational Technology	1
Cogent Engineering	1
Cybersecurity and Innovative Technology Journal	1
Educational Process: International Journal	1
Educational Technology & Society	1
International Journal of Computer Applications	1
International Journal of STEM Education	1
International Research Journal of Multidisciplinary Technovation	1
Journal of Artificial Intelligence, Machine Learning and Neural Network	1
Journal of Educational Technology & Society	1
Journal of Engineering Science & Technology Review	1
Journal of Information Systems Education	1
Journal of New Approaches in Educational Research	1
Metaverse Basic and Applied Research	1
Technology Innovation Management Review	1

Figure 2 depicts the distribution of articles published from 2018 to 2023. The majority of these articles, eleven in total, were published in 2023. The year 2022 saw the publication of seven articles, representing the second-highest count. Two articles were published in 2021, while 2020 and 2019 saw the publication of one and four articles, respectively. No articles were published in 2018.

The overall trend in publications (represented by the dotted line in Figure 2) indicates that researchers have shown widespread interest in artificial intelligence in education and ITSs over the last two years, and this interest is expected to increase in the future. The excitement surrounding ChatGPT seems to be the cause of it.

Five of the 25 articles were empirical studies, and the rest were non-empirical studies, including 14 systematic reviews and meta-analyses, two bibliometric analyses, two critical reviews, one definition paper, and one conceptual analysis.

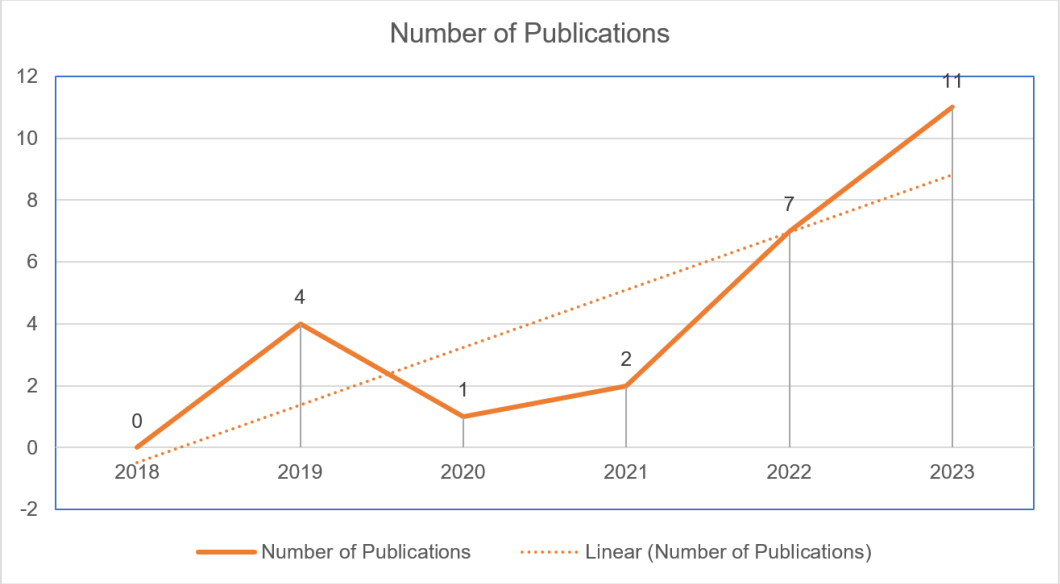
The articles included in this review are derived from eleven countries and distributed as follows. There is one article each from Greece, Spain, Pakistan, Philippines, Taiwan, and the United Kingdom. Additionally, there are two articles each from Germany, India, and the United Arab Emirates. Furthermore, there are six articles originating from the United States and seven from China, indicating that these two countries are currently at the forefront of AI research in education and the advancement of ITSs, particularly in higher education. All studies in this systematic review were published in peer-reviewed journals in English.

3.1 Guiding question 1: How have Intelligent Tutoring Systems evolved in the last five years?

The research indicates that the prominent themes regarding the evolution of ITSs can be categorized as follows: 1) integration of AI; 2) personalized and adaptive learning; 3) learning analytics; 4) inclusion and equity; and 5) STEM disciplines. In particular, all the studies pointed out that ITSs are one of the critical applications of AI technologies in education. This finding suggests that the recent advancement of ITSs has centered around the integration of AI, or in simpler terms, powering ITSs with AI capabilities.

ITSs have been developed and evaluated over the years. While they have utilized certain AI techniques, recent advancements in AI, particularly in generative AI, appear to be revolutionizing the field. Bahroun et al. (2023) pointed out that ITSs now use generative artificial intelligence to adapt to individual student needs, and ChatGPT is an example of

Figure 2. Number of publications from 2018 to 2023



a dominant tool in the current landscape of ITSs. Gupta and Chen (2022) stated that these systems have grown from simple computer programs to advanced AI chatbots that understand and interact with students, and the advancement of natural language processing and deep learning has been crucial in making chatbots more intelligent. Similarly, Xie et al. (2021) concluded that ITSs have evolved from rule-based or statistical learning models to deep learning models, and modern AI enables intelligent tutors to act not just as teaching tools or tutors but also as learning partners and advisors. They further argued that the shift to modern AI in education is leading to a reconceptualization of pedagogical frameworks, which appears to be a bold claim that needs to be studied long-term. Kamalov et al. (2023) found that the efficiency of ITS has improved with AI's ability to automate tasks like grading and content creation. Ipek et al. (2023) reported that ITSs can now create individualized educational content quickly and efficiently by utilizing generative AI. Thus, it has become more personalized and adapts to students' interests and abilities. These findings suggest that the integration of AI, particularly generative AI, in ITSs will continue to grow.

In the last five years, there has been an evolution in the field of ITSs with more focus on personalized and adaptive learning experiences. Modern ITSs can diagnose student knowledge gaps and provide automated feedback, including functions like curating learning materials based on student profiles (Zawacki-Richter et al., 2019). AI helps identify students who might need extra help and supports them early (Salas-Pilco et al., 2022). Predictive models in these systems identify at-risk students, those who might drop out or need additional assistance, and suggest interventions (Nagaraj et al., 2023) or assist in predicting student performance, progress, and emotions toward learning (Crompton & Burke, 2023). All these findings are crucial in supporting positive learning outcomes.

Additionally, Chu et al. (2022) also found that the growth of adaptive ITSs has been significant, with a focus on improving learning effectiveness and understanding learners' feelings. However, whether AI will ever be able to understand human interactions, emotions, or feelings genuinely is yet another research topic that needs to be explored further. Chen et al. (2022) concurred that the evolution of ITSs indicates a trend towards greater personalization in education, helping instructors create effective learning experiences. This suggests that the role of instructors is essential in the future development of ITSs. In addition, du Boulay (2019) pinpointed that ITSs have evolved from focusing on one-on-one skill tutoring to more complex dialog-based interactions by incorporating generative AI. Through that, modern ITSs consider students' feelings, encourage them through various teaching methods, and offer feedback on what students know and how they think.

Moreover, the use of ITSs has expanded to help manage a whole class, not just individual students (Crompton & Burke, 2023), and technologies such as eye-tracking have been used to identify learning methods and improve the recognition of different learner approaches (Jing et al., 2023). It should be emphasized that managing a group of students, rather than

https://doi.org/10.21428/8c225f6e.33570bb1

individuals, with AI-powered ITSs can be considered a significant advancement in education. Renz and Vladova (2021) concluded that ITSs have evolved to use AI for personalized instruction and feedback without a human teacher and include methods where teachers can teach an AI system to teach students. Although this may seem revolutionary, it is important to note that AI has yet to genuinely comprehend conversations or connect with students, which will be discussed later in the paper.

In 2020, the COVID-19 pandemic further emphasized the need for ITSs to support remote learning and provide in-depth analysis of large datasets to guide educational stakeholders. Thus, the development of ITSs has shifted towards intelligent analytics systems, leveraging big data analytics and AI techniques to provide adaptive guidance programs for teachers, students, families, and schools (Shi et al., 2022). They further claimed that learning analytics will play a crucial role in the future of ITSs, enabling the collection and analysis of large datasets to inform instructional decisions, identify learning gaps, and provide personalized interventions. Similarly, Abbas et al. (2023) found that advancements in AI have enabled ITSs to predict student performance and offer tailored support, and these systems use data analytics to identify at-risk students and intervene early. There is more use of AI for learning analytics and automated instruction in ITSs to provide more personalized and adaptive learning experiences (Triplett, 2023). These findings were expected, and it is natural that ITSs would evolve towards learning analytics as generative AI is trained and operates on large amounts of data.

Inclusion and equity seem to be another evolutionary trend regarding the development of ITSs with generative AI. AI and deep learning techniques like neural networks have made ITSs more effective in various educational applications (Xie et al., 2021), and the design of ITSs is becoming more culturally aware to support diverse student backgrounds (Salas-Pilco et al., 2022). Alam and Mohanty (2023) reported that ITSs have evolved to provide personalized and adaptive support to learners regardless of location or socioeconomic background. These systems can be accessed from anywhere, helping all students. Similarly, Gupta and Chen (2022) found that educational chatbots now aim to support inclusive learning by being accessible, interactive, and confidential. They are designed to mimic and extend the classroom setting, offering a more fair and interactive way of learning. Chatbots, a type of intelligent tutoring system, are now being tested to see how they can support students in a way that includes everyone, no matter their background or learning preferences.

Additionally, García-Martínez et al. (2023) found that ITSs support special education and help students with special needs by giving them tailored learning experiences. The focus now is on creating transparent models that can be trusted and are free from biases (Bahroun et al., 2023). These findings are of utmost importance due to the fact that technological advancements like generative AI can enable more inclusive and equitable education for everyone. However, there is a lack of primary studies, especially with a focus on inclusion and equity, in the context of ITSs.

STEM subjects have influenced the development of ITSs due to their suitability for such educational technology (Renz & Vladova, 2021), and the integration of generative AI is no different. As discussed earlier, ITSs in higher education have been recognized as effective AI applications (Crompton & Burke, 2023), and ITSs have evolved to enhance personalized and adaptive learning in STEM education (Xu & Fan, 2022). They can increase interest in subjects like STEM or STEAM (Science, Technology, Engineering, Arts, and Math) by using engaging emerging technologies (Salas-Pilco et al., 2022). For example, Qian Cao et al. (2022) found that virtual simulation teaching methods, resources, and learner experiences can significantly improve engineering students' motivation and learning. Moreover, it has been found that virtual simulation can make learning safer and more hands-on, especially for subjects like chemistry and physics. However, more research is needed to explore how ITSs and generative AI affect non-STEM disciplines, which is an intriguing research area.

In conclusion, ITSs are developing fast, with a growing emphasis on generative AI, personalized and adaptive learning, learning analytics, inclusion and equity, and STEM disciplines.

3.2 Guiding question 2: How effective are the current available AI-powered tutors?

ITSs powered by AI have been found to be effective in enhancing student learning outcomes. Research has shown that students who receive personalized instruction through AI-powered ITSs demonstrate higher levels of engagement, improved academic performance, and increased knowledge retention compared to traditional classroom settings (Kumar et al., 2023). These systems analyze student data, such as performance and task-related preferences, to generate tailored content and recommendations, optimizing learning outcomes (Kamalov et al., 2023). They have been particularly effective in STEM education, where they have helped students develop problem-solving abilities and conceptual understanding. However, it is important to note that the

effectiveness of ITSs may vary depending on factors such as the specific implementation, instructional practices, and the effects of new technological integrations.

Further research is needed to explore the long-term effectiveness and compare it to other instructional methods (Wang et al., 2020). Most of the implementation and validation of ITS presented in the studies took place over short-term periods, such as a course or a semester, and no longitudinal studies were identified (Zawacki-Richter et al., 2019). Research is ongoing to see how AI tutors affect students' long-term success (Triplett, 2023). This indicates a gap in the literature regarding the long-term effectiveness and impact of ITSs on learning outcomes.

In contrast, despite the advancements, ITSs have shown no significant difference in learning effect, indicating a need for quality over quantity (Qian Cao et al., 2022). The goal is to create systems that assist in learning and contribute to the science of learning by providing actionable insights (Rosé et al., 2019). While there is a need for more research on the effectiveness of ITS, research has indicated that ITSs have a moderate effect on students' learning but outperform traditional instruction methods (Renz & Vladova, 2021). When measuring their effectiveness, it is important to consider the limitations of ITSs, such as their inability to conduct natural language dialogues or understand the subject being taught and the need for adjustment to different learners (Nagaraj et al., 2023). Thus, the integration of generative AI into ITSs may hold great promise for the future of these systems. Generative AI can analyze vast amounts of data, such as learner performance and learning preferences, to generate customized content and recommendations, further enhancing the learning outcome. Additionally, they may use data mining to understand how students learn and behave (Xu & Fan, 2022). Overall, more research is needed to fully understand the effectiveness of ITSs in different educational contexts and technology integrations.

3.3 Guiding question 3: What could the next generation of Intelligent Tutoring Systems look like?

As discussed in the first guiding question, the research suggests that the future of ITSs lies in the integration of advanced technologies such as AI, generative AI, machine learning, and natural language processing to provide more personalized and adaptive learning experiences. All studies predicted that they would shift from AI-enabled to increasingly AI-powered, enhancing the ITSs' abilities to understand and adapt to learners. Besides generative AI, Renz and Vladova (2021) reported that ITSs will likely focus on human-centered AI, enhancing human capabilities alongside AI technology. Additionally, emerging technologies, including virtual reality, augmented reality, robots/avatars, and voice assistants, will likely play crucial roles in the next generation of these systems. Emphasis on remote and online learning, inclusion and equity, and gamification have also been reported. Jing et al. (2023) concluded that ITSs will continually evolve as new technologies come out.

Wang et al. (2020) indicated that AI-powered virtual reality (VR) applications provide immersive learning environments where students can explore complex concepts and engage in active learning virtually. Qian Cao et al. (2022) reported that the use of VR in teaching has become possible due to advancements in technology, and these VR systems now offer high simulation degree scenes for vivid reproduction of real-life scenarios. It makes learning experiences feel like real life and provides students with hands-on experiences that are not possible in traditional classrooms. They continued that theories like constructivism and self-regulated learning have influenced the development of virtual teaching systems and the utilization of VR in ITSs. Nagaraj et al. (2023) found that the integration of ITSs, AI models, and the Metaverse (a virtual environment), holds great potential for transforming education by delivering personalized learning experiences, fostering collaboration, and providing timely feedback. However, it is noted that challenges include designing effective AI algorithms and ensuring realistic virtual simulations. Additionally, Kumar et al. (2023) found that the latest ITSs can even work in virtual worlds like the Metaverse, while Abbas et al. (2023) pinpointed that the role of ITS has expanded to include collaborative learning environments and virtual classrooms.

On the other hand, augmented reality (AR) can also be used to create immersive learning experiences, allowing students to explore and analyze complex concepts within their own surroundings (Kamalov et al., 2023). It also fosters student engagement with the authentic world. It bridges the gap between theory and practice, enabling students to connect abstract concepts taught in the classroom with real-world applications (du Boulay, 2019). Additionally, AR in ITS facilitates collaborative problem-solving and knowledge co-construction, promoting social interaction, teamwork, and the development of critical thinking and communication skills (Alam & Mohanty, 2023). The integration of augmented reality and virtual reality in ITSs promotes active learning experiences and has the potential to enhance engagement, comprehension, and collaboration, leading to improved learning outcomes and a more enriched educational journey.

https://doi.org/10.21428/8c225f6e.33570bb1

Therefore, it is safe to say both virtual reality and augmented reality will likely play a significant role in creating immersive and personalized learning environments within the next generation of ITSs.

Robots are being used in ITSs to facilitate students' learning experiences and allow them to acquire knowledge in interactive ways (Zawacki-Richter et al., 2019). Educational robots, including programming robots and social robots, are commonly used in STEM education as instructional tools or educational subjects, and avatars are being utilized as a form of AI assistance (Xu & Fan, 2022). Programming robots allow learners to design and operate them with programming languages, while social robots, such as intelligent humanoid robots, serve as tutors or learning companions to students, allowing them to interact orally and physically (Wang et al., 2020). These AI-supported robots in STEM education provide opportunities to convey knowledge, promote students' operational skills, and enhance their learning experience (Kamalov et al., 2023). Additionally, the design of ITSs now includes human-like avatars and gamification to make learning more engaging (Bahroun et al., 2023), and these avatars can take on anthropomorphic forms or appear as text prompts, depending on the design and purpose of the ITS (Nagaraj et al., 2023). The role of avatars in ITSs aligns with the Zone of Proximal Development (ZPD) concept, where students can rapidly develop with assistance (Crompton & Burke, 2023). Besides, voice assistants can help students develop soft skills by engaging in meaningful conversations and asking thought-provoking questions that promote critical thinking (Gupta & Chen, 2022). The use of voice agents in ITSs expands the capabilities of chatbots and provides opportunities for personalized and inclusive learning environments (du Boulay, 2019). Overall, AI avatars, robots, and voice assistants are increasingly incorporated in ITSs to provide timely support, consider students' abilities and preferences, and tailor strategies for learning. However, widespread adoption or usage in everyday educational settings may still be far away due to the emerging nature and high cost of these technologies.

The integration of games with adaptive learning and ITSs has become a key approach for engaging young learners, and they not only enhance students' performance but also improve their attitudes and self-efficacy (Jing et al., 2023). Game-based tutoring systems have been found to positively impact learning outcomes, with increased engagement and improved problem-solving skills (Crompton & Burke, 2023). ITSs, combined with AI, can further enhance the gamification experience by personalizing educational activities and strategies based on learners' characteristics and needs (Alkhatlan & Kalita, 2019). As a result, the integration of games in ITSs offers innovative and engaging educational interactions beyond traditional teaching methods.

It is likely that ITSs will continue to evolve to increasingly support remote and online learning, inclusion, and equity. Future ITSs could be more available, helping students everywhere, and they may focus on being fair and safe for all users (Kumar et al., 2023). Advances in technology could make these systems available all the time, helping students whenever they need it (Gupta & Chen, 2022). ITSs could become more widely available, helping students all over the world (Qian Cao et al., 2022). Remote and online learning in ITSs provides access to quality education in remote or underserved areas, reaching students who may not have access to traditional educational resources (Zawacki-Richter et al., 2019). Also, it saves time and cost by automating certain aspects of instruction and support, reducing the need for one-on-one tutoring (Wang et al., 2020).

Additionally, remote learning in ITSs allows for multimodal learning, incorporating various forms of multimedia such as videos, interactive simulations, and virtual environments to engage students and enhance their learning experience (Nagaraj et al., 2023). Lastly, it employs cognitive techniques like spaced repetition and Cognitive Load Theory to promote long-term retention of knowledge and skills (Kamalov et al., 2023). These make remote and online learning in ITSs a valuable tool for providing equitable and effective education today and in the future.

3.4 Guiding question 4: What are the opportunities and limitations of AI-powered tutors to complement the role of human tutors?

Intelligent tutoring systems (ITSs) can complement human tutors by providing personalized instruction and support to learners (Zawacki-Richter et al., 2019). Future ITSs will use AI not just to adapt and predict but also to explain why certain learning methods work; they will get better at giving advice that learners will actually want to follow (Rosé et al. 2019). ITSs have evolved to use multimedia to present information and motivate students (Alkhatlan & Kalita, 2019). By simulating human tutoring and adapting to individual learning preferences, pace, and preferences, ITSs enhance learner engagement, boost learning outcomes, and offer immediate and targeted assistance (Shi et al., 2022). While human tutors bring their expertise and interpersonal skills, ITSs leverage AI algorithms to provide tailored instruction and guidance, optimizing the learning process for each learner (Kumar et al., 2023). Furthermore, AI in tutoring

systems has evolved to support collaborative and social learning, and AI will help make sure that the way learners are taught is fair and good for everyone (Nagaraj et al., 2023). Therefore, the combination of human tutors and ITSs can create a comprehensive and effective learning environment.

In contrast, ITSs have limitations compared to human tutors. One limitation is that ITSs may lack the ability to conduct natural language dialogues with learners, understand the subject being taught, and accept unanticipated responses (Zawacki-Richter et al., 2019). They may also struggle to understand the nature of students' mistakes or misconceptions and cannot profit from experience with learners or experiment with teaching strategies. It was noted that ITSs were less effective than human tutoring but outperformed other instruction methods, such as traditional classroom instruction or homework assignments (Wang et al., 2020). Another limitation is the potential lack of empathy and appropriate response in sensitive situations, as AI systems may not have the same level of understanding of human interaction, emotions, and context as human tutors (Shi et al., 2022). Similarly, ethical decision-making in AI integration involves considering the potential risks and unintended consequences associated with the use of AI systems, which requires ongoing monitoring and evaluation by educators (Nagaraj et al., 2023). Ethical issues are becoming a big concern as AI uses lots of data and personal information to operate. There will be a greater emphasis on the ethical use of data and protecting learner privacy, and in some cases, human oversight is crucial to provide the necessary support and guidance that AI systems may not be equipped with. Thus, the development of ITSs should prioritize human values and dignity to ensure the responsible implementation of AI in educational settings (Renz & Vladova, 2021).

ITSs will likely continue to grow and become more common in higher education (Crompton & Burke, 2023). Despite their potential, the actual use of ITSs in education, especially in developing countries, is still low, mainly because ITSs are still new to many educators, and there is a general distrust towards AI technology (Wang et al., 2020). Trust in the technology and how well it works with current teaching methods are important for educators and instructors to recognize ITSs' advantages and decide how to use them (Wang et al., 2020). Research is being done to find out what makes educators want to use these AI-powered systems. Thus, ITSs could become better at working with teachers to help learners (Kamalov et al., 2023) instead of focusing on individual learners. Future ITSs could involve more teacher-AI collaboration, where teachers input their expertise into the system (Renz & Vladova, 2021). ITSs will likely continue to blend with traditional teaching, supporting teachers rather than replacing them (du Boulay, 2019). Thus, as we move forward, ensuring that ITSs complement, rather than replace, the essential role of human tutors is essential.

4. Discussion and conclusion

There is a lack of research regarding AI applications in education settings, especially on whether generative AI can effectively advance intelligent tutoring and begin a new era of AI-powered effective tutors. Considering that there are industry efforts like Khanmigo (Khan Academy, 2023), an AI-powered tutor, which is a collaboration between Khan Academy and OpenAI (see Figure 3), and Socratic (Google, 2018), a learning app powered by Google AI (see Figure 4), the purpose of this study was to investigate deeper into the possibilities, challenges, and implications of using AI-powered tutors, previously known as intelligent tutor systems (ITSs).

This systematic literature review extensively explores ITSs and their evolution, current, and potential use in higher education STEM disciplines. It also discusses how the possible integration of generative AI into ITSs marks a transformative leap in teaching and learning and its advantages and disadvantages. The main questions that guided this review were:

1. How have intelligent tutoring systems evolved in the last five years (2018-2023)?
2. How effective are the current available AI-powered tutors?
3. What could the next generation of intelligent tutoring systems look like?
4. What are the opportunities and limitations of AI-powered tutors to complement the role of human tutors?

The research identified five prominent themes regarding the evolution of ITSs in the last five years: 1) integration of AI; 2) personalized and adaptive learning; 3) learning analytics; 4) inclusion and equity; and 5) STEM disciplines. In particular, it was found that ITSs are one of the key applications of AI technologies in education. Moreover, students who receive personalized instruction through AI-powered ITSs have demonstrated higher levels of engagement, improved academic performance, and increased knowledge retention compared to traditional classroom settings. A recent study (Niño-Rojas et al., 2024) examining trends in

https://doi.org/10.21428/8c225f6e.33570bb1

Figure 3. Example of a Khanmigo use case (Khan Academy, 2023)

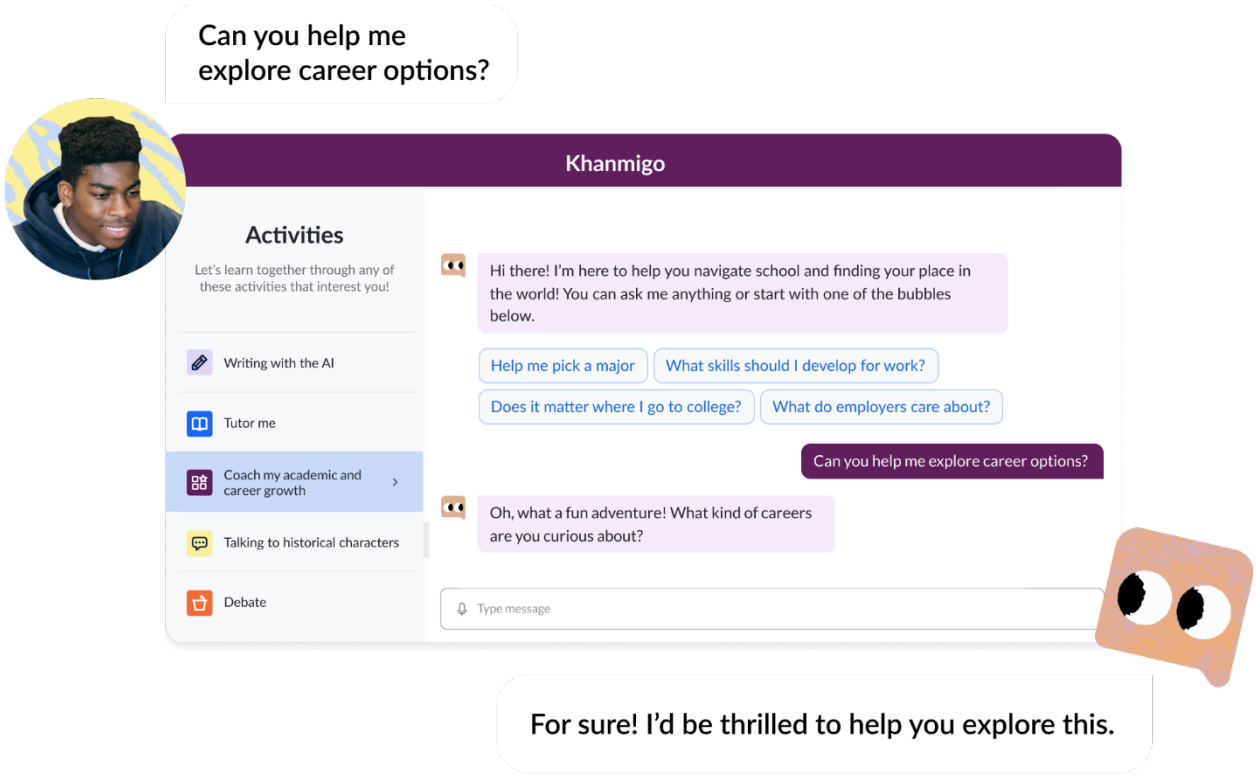
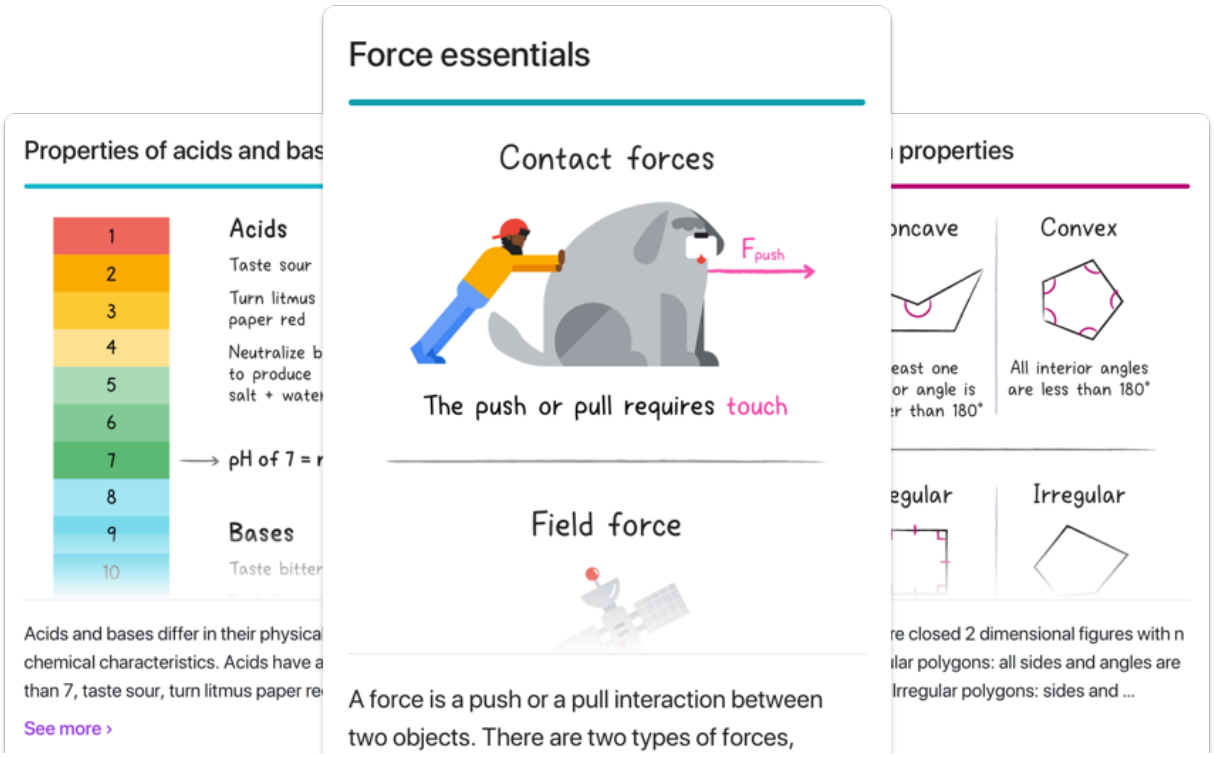


Figure 4. Examples of a Socratic by Google use case (Google, 2018)



ITSs for mathematics teaching and learning in secondary and higher education found that ITSs improved academic performance by 37.2% and student learning by 18.6%, respectively. Such suggests that ITSs are effective in higher education STEM discipline settings.

Studies reviewed show that emerging technologies, including virtual reality, augmente reality, robots/avatars, and voice assistants, will likely play crucial roles in the next generation of these systems. Additionally, emphasis on online and remote learning, gamification, inclusion, and equity aspects were identified. The research suggests that combining human tutors and ITSs can create a more comprehensive and effective learning environment rather than solely relying on ITSs or human tutors. However, the findings suggest a limitation: AI systems may not have the same level of understanding of human interaction. Therefore, ethical issues are becoming a big concern due to the enormous data usage of AI, specifically personal and other sensitive information. It is anticipated that the ethical use of data and the protection of learner privacy will receive more attention, but it is unclear how they will be addressed. In some situations, human oversight may be essential to provide AI systems the assistance and direction they may lack. Additionally, ITSs are still new to many educators, and there is a general distrust toward AI technology. Due to these limitations, a low adoption rate of ITSs has been reported, and long-term studies are scarce, but it is necessary to explore how these issues will evolve or be addressed.

4.1 Future research

Although the term intelligent tutoring systems (ITSs) has been used for decades, the combination of generative AI and ITSs is still in its infancy, considering ChatGPT's public release in November 2022. As discussed earlier, more longitudinal research is needed to fully understand the long-term effectiveness and impact of generative AI-powered ITSs on learning outcomes, as well as the adoption, general attitude, and trust of educators and learners toward this technology. Additionally, more research is needed to fully understand the effectiveness of generative AI-powered ITSs in different educational contexts besides STEM and with various emerging technology integrations such as virtual/augmented reality, robots, and voice assistants.

In conclusion, since the future of education is undoubtedly AI-augmented, this systematic literature review evaluates how crucial it is to responsibly harness generative AI and ITSs. As we move forward, ensuring that ITSs complement, rather than replace, the essential role of human tutors is vital. While the rise of generative AI in education presents transformative potential, it is also essential to maintain a balance. Human connection, mentorship, and collaboration remain vital to fostering critical and analytical thinking, creativity, and communication skills. Therefore, as ITSs and AI-based tools become more prevalent, they should complement—not replace—the rich, interpersonal elements of learning that have always been the core of education. Together, human-to-human interaction and AI can create a more holistic and future-ready learning environment.

4.2 Limitations of this review

Most studies selected for this systematic review are secondary research, not primary, which is one of the limitations of this review. Although secondary research data can be insightful, relying solely on pre-existing information may restrict the study and limit the exploration of new perspectives. Additionally, this study focused exclusively on peer-reviewed journal articles. Other forms of scholarly publications, such as non-peer-reviewed journal articles, book chapters, reports, dissertations, conference proceedings, blog posts, industry insights, and forecasts, may have provided more valuable and cutting-edge information because generative AI is an emerging technology that is still being actively developed and experimented with. Third, conducting a review in educational settings other than higher education might yield different results, considering the existing AI tutors like Khanmigo (Khan Academy, 2023) are mainly designed for children under 18 years. As a result, future research could focus more on primary research while also expanding to other forms of literature in the literature review and possibly exploring other educational settings. More primary data collection presents the possibility to capture real-time nuances and contextual details that could enhance the overall strength of the study.

4.3 Implications for practice

The findings from this systematic literature review highlight the next generation of ITSs, leveraging generative AI and other emerging technologies such as virtual reality, augmented reality, robots/avatars, and voice assistants. These innovations not only improve instructional delivery but also help make learning experiences more immersive and engaging. The emphasis has also been placed on remote and online learning, inclusion and equity, and gamification. These insights contribute to the ongoing research and development process, aiming to refine these systems to be more intuitive, context-aware, fair, and responsive to diverse learners and their individual needs. As education becomes

increasingly digital, these elements are critical to ensuring that AI-powered systems meet the diverse needs of students, regardless of location, socioeconomic background, or learning preferences.

The adoption of AI is accelerating in higher education. According to Microsoft (2020), 99.4% of 509 higher education institutions surveyed in the U.S. believe that AI will be essential to their institution's competitiveness, with 54% already experimenting with it. Complementing this, the World Economic Forum (2023) *Future of Jobs Report* projects that by 2027, AI and automation will transform the nature of education, fostering new learning models that emphasize problem-solving, creativity, and adaptive thinking. The report highlights how AI-powered systems in higher education could drive significant shifts in pedagogy, enabling universities to deliver more personalized, data-driven, and scalable learning experiences, resulting in a growth of jobs in higher education.

Consequently, the findings of this literature review may help shape policies that address the ethical and practical implementation of AI-powered tutoring and teaching systems in higher education. They highlight the need to address the ethical challenges associated with AI-powered tutoring and teaching systems, including issues related to data privacy, algorithmic bias, and equitable access.

However, it is essential to acknowledge that generative AI is still largely experimental and developing at an unexpectedly rapid pace. The future remains uncertain, but generative AI will either be utilized or at least attempted to be incorporated in nearly every facet of education. The potential of AI to revolutionize learning environments, enhance accessibility, and offer personalized experiences is here. It is up to us to use it adequately and for the public good. Yet, the historical skepticism of education systems towards the rapid adoption of new technologies, particularly AI, emphasizes the need for ongoing research and thoughtful policymaking as we move toward an AI-enhanced educational future.

References

Abbas, N., Ali, I., Manzoor, R., Hussain, T., & Hussain, M. H. A. i. (2023). Role of artificial intelligence tools in enhancing students' educational performance at higher levels. *Journal of Artificial Intelligence, Machine Learning and Neural Network*, 3(5), 36–49. https://doi.org/10.55529/jaimlnn.35.36.49

Alam, A., & Mohanty, A. (2023). Educational technology: Exploring the convergence of technology and pedagogy through mobility, interactivity, AI, and learning tools. *Cogent Engineering*, *10*(2), 1–37. https://doi.org/10.1080/23311916.2023.2283282

Alkhatlan, A., & Kalita, J. (2019). Intelligent tutoring systems: A comprehensive historical survey with recent developments. *International Journal of Computer Applications*, *181*(43), 1–20. https://doi.org/10.5120/ijca2019918451

Bahroun, Z., Anane, C., Ahmed, V., & Zacca, A. (2023). Transforming education: A comprehensive review of generative artificial intelligence in educational settings through bibliometric and content analysis. *Sustainability*, *15*(17), 12983. https://doi.org/10.3390/su151712983

Chen, X., Zou, D., Xie, H., Cheng, G., & Liu, C. (2022). Two decades of artificial intelligence in education: Contributors, collaborations, research topics, challenges, and future directions. *Educational Technology & Society*, *25*(1), 28–47. https://doi.org/10.30191/ETS.202201_25(1).0003

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

Collins, K., & Lanxon, A. (2024, January 10). *Biggest Trends of CES 2024: AI, Transparent Screens and Off-Grid Tech to Power Your Home*. CNET. Accessible at: https://www.cnet.com/tech/biggest-trends-of-ces-2024-ai-transparent-screens-and-off-grid-tech-to-power-your-home/

Correia, A.-P. (2023, March 15). *Is ChatGPT the new buzz in Higher Education?* Accessible at: https://www.ana-paulacorreia.com/anapaula-correias-blog/2023/3/15/is-chatgpt-the-new-buzz-in-higher-education

Crompton, H., & Burke, D. (2023). Artificial intelligence in higher education: The state of the field. *International Journal of Educational Technology in Higher Education*, *20*(1), 1–22. https://doi.org/10.1186/s41239-023-00392-8

du Boulay, B. (2019). Escape from the Skinner Box: The case for contemporary intelligent learning environments. *British Journal of Educational Technology*, *50*(6), 2902–2919. https://doi.org/10.1111/bjet.12860

García-Martínez, I., Fernández-Batanero, J. M., Fernández-Cerero, J., & León, S. P. (2023). Analysing the impact of artificial intelligence and computational sciences on student performance: Systematic review and meta-analysis. *Journal of New Approaches in Educational Research, 12*(1), 171–197. https://doi.org/10.7821/naer.2023.1.1240

Goldman Sachs (2023, August 1). *AI investment forecast to approach $200 billion globally by 2025*. Goldman Sachs. Accessible at: https://www.goldmansachs.com/intelligence/pages/ai-investment-forecast-to-approach-200-billion-globally-by-2025.html

Google. (2018). *Get unstuck. Learn better.* Google Socratic. https://socratic.org

Government Technology. (2023, May 25). *Is ChatGPT Better Than a Human Tutor? Survey Says ... Yes*. GovTech. Accessible at: https://www.govtech.com/education/k-12/is-chatgpt-better-than-a-human-tutor-survey-says-yes

Grossman, N. (2023, May 18). *AI won't replace teachers, but it can make them more effective*. The Thomas B. Fordham Institute. Accessible at: https://fordhaminstitute.org/national/commentary/ai-wont-replace-teachers-it-can-make-them-more-effective

Guo, L., Wang, D., Gu, F., Li, Y., Wang, Y., & Zhou, R. (2021). Evolution and trends in intelligent tutoring systems research: A multidisciplinary and scientometric view. *Asia Pacific Education Review*, *22*(3), 441–461. https://doi.org/10.1007/s12564-021-09697-7

Gupta, S., & Chen, Y. (2022). Supporting inclusive learning using chatbots? A chatbot-led interview study. *Journal of Information Systems Education*, *33*(1), 98–108. https://aisel.aisnet.org/jise/vol33/iss1/11/

Ipek, Z. H., Gözüm, A. I. C., Papadakis, S., & Kallogiannakis, M. (2023). Educational applications of the ChatGPT AI system: A systematic review research. *Educational Process: International Journal*, *12*(3), 26–55. https://doi.org/10.22521/edupij.2023.123.2

Jing, Y., Zhao, L., Zhu, K., Wang, H., Wang, C., & Xia, Q. (2023). Research landscape of adaptive learning in education: A bibliometric study on research publications from 2000 to 2022. *Sustainability*, *15*(4), 3115. https://doi.org/10.3390/su15043115

Kamalov, F., Santandreu Calonge, D., & Gurrib, I. (2023). New era of artificial intelligence in education: Towards a sustainable multifaceted revolution. *Sustainability*, *15*(16), 12451. https://doi.org/10.3390/su151612451

Khan Academy. (2023). *Meet Khanmigo, Khan Academy's AI-powered teaching assistant & tutor*. Accessible at: https://khanmigo.ai/

Kumar, D., Haque, A., Mishra, K., Islam, F., Mishra, B. K., & Ahmad, S. (2023). Exploring the transformative role of artificial intelligence and metaverse in education: A comprehensive review. *Metaverse Basic and Applied Research, 2,* 55. https://doi.org/10.56294/mr202355

Lv, Z. (2023). Generative artificial intelligence in the metaverse era. *Cognitive Robotics*, *3*, 208–217. https://doi.org/10.1016/j.cogr.2023.06.001

Manaware, D. (2020). Artificial Intelligence: A New Way to Improve Indian Agriculture. *International Journal of Current Microbiology and Applied Sciences*, *9*(3), 1095–1102. https://doi.org/10.20546/ijcmas.2020.903.128

Microsoft. (2020). *New IDC report shows big opportunities to transform higher education through AI*. Microsoft Education Blog. Accessible at: https://educationblog.microsoft.com/en-us/2020/03/new-idc-report-shows-big-opportunities-to-transform-higher-education-through-ai

Nagaraj, B. K., Kalaivani, A., Suraj Begum, R., Akila, S., Sachdev, H. K., & Senthil Kumar, N. (2023). The emerging role of artificial intelligence in STEM higher education: A critical review. *International Research Journal of Multidisciplinary Technovation, 5*(5), 1–19. https://doi.org/10.54392/irjmt2351

Niño-Rojas, F., Lancheros-Cuesta, D., Jiménez-Valderrama, M. T. P., Mestre, G., & Gómez, S. (2024). Systematic Review: Trends in Intelligent Tutoring Systems in Mathematics Teaching and Learning. *International Journal of Education in Mathematics, Science and Technology*, *12*(1), 203–229. https://doi.org/10.46328/ijemst.3189

OpenAI. (2018). *Improving language understanding with unsupervised learning*. OpenAI. Accessible at: https://openai.com/research/language-unsupervised

Psotka, J., Massey, L. D., & Mutter, S. A. (1988). *Intelligent Tutoring Systems: Lessons Learned*. Lawrence Erlbaum Associates. https://psycnet.apa.org/record/1988-97858-000

Qian Cao, Ye Huang, Tingting Luo, & Lei Liu. (2022). Effect of virtual simulation teaching system on learning of students majoring in engineering technology. *Journal of Engineering Science & Technology Review*, *15*(3), 227–232. https://doi.org/10.25103/jestr.153.25

Renz, A., & Vladova, G. (2021). Reinvigorating the discourse on human-centered artificial intelligence in educational technologies. *Technology Innovation Management Review*, *11*(5), 5–16. https://doi.org/10.22215/timreview/1438

Rosé, C. P., McLaughlin, E. A., Liu, R., & Koedinger, K. R. (2019). Explanatory learner models: Why machine learning (alone) is not the answer. *British Journal of Educational Technology*, *50*(6), 2943–2958. https://doi.org/10.1111/bjet.12858

Salas-Pilco, S. Z., Xiao, K., & Oshima, J. (2022). Artificial intelligence and new technologies in inclusive education for minority students: A systematic review. *Sustainability*, *14*(20), 13572. https://doi.org/10.3390/su142013572

Selwyn, N. (2021). *Education and Technology: Key Issues and Debates*. Bloomsbury. https://books.google.com/books?id=csZKEAAAQBAJ

Shi, D., Zhou, J., Wang, D., & Wu, X. (2022). Research status, hotspots, and evolutionary trends of intelligent education from the perspective of knowledge graph. *Sustainability (2071-1050)*, *14*(17), 10934. https://doi.org/10.3390/su141710934

Smolansky, A., Cram, A., Raduescu, C., Zeivots, S., Huber, E., & Kizilcec, R. F. (2023). Educator and Student Perspectives on the Impact of Generative AI on Assessments in Higher Education. *Proceedings of the Tenth ACM Conference on Learning @ Scale*, (pp. 378–382). https://doi.org/10.1145/3573051.3596191

Triplett, W. J. (2023). Artificial intelligence in STEM education. *Cybersecurity and Innovative Technology Journal, 1*(1), 23-29. https://doi.org/10.53889/citj.v1i1.296

Wadhwani, P. (2023). *AI in education market statistics, trends & growth opportunity 2032*. Global Market Insights. Accessible at: https://www.gminsights.com/industry-analysis/artificial-intelligence-ai-in-education-market

Wang, S., Yu, H., Hu, X., & Li, J. (2020). Participant or spectator? Comprehending the willingness of faculty to use intelligent tutoring systems in the artificial intelligence era. *British Journal of Educational Technology*, *51*(5), 1657–1673. https://doi.org/10.1111/bjet.12998

Weitekamp, D., Harpstead, E., & Koedinger, K. R. (2020). An Interaction Design for Machine Teaching to Develop AI Tutors. *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, 1–11. https://doi.org/10.1145/3313831.3376226

World Economic Forum. (2023). *The Future of Jobs Report 2023*. World Economic Forum. Accessible at: https://www.weforum.org/publications/the-future-of-jobs-report-2023/digest/

Xie, H., Hwang, G.-J., & Wong, T.-L. (2021). Editorial Note: From Conventional AI to Modern AI in Education: Re-examining AI and Analytic Techniques for Teaching and Learning. *Educational Technology & Society*, *24*(3), 85–88. https://www.jstor.org/stable/27032857

Xu, W., & Fan, O. (2022). The application of AI technologies in STEM education: A systematic review from 2011 to 2021. *International Journal of STEM Education*, *9*(59), 1–20. https://doi.org/10.1186/s40594-022-00377-5

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

Disclaimer

Using company names and/or any mention or listing of particular commercial products or services herein is purely for educational purposes and to better illustrate the authors' point of view. The authors do not endorse, nor do they discriminate against, comparable products or services that are not mentioned.

About the authors



Batzaya (Zack) Batsaikhan

Batzaya (Zack) Batsaikhan is a doctoral student of Learning Technologies at The Ohio State University in Columbus, Ohio, United States. He earned his M.Sc. in Human-Computer Interaction from Iowa State University on a Fulbright Scholarship and has over ten years of industry experience in designing and implementing human-centered digital products and services. His current research interests include entrepreneurship in learning technologies, learner experience design, applications of emerging technologies in education (AI/AR/VR), and human-computer interaction.

batsaikhan.6@osu.edu
0009-0002-7506-4271
https://www.batzaya.net



Ana-Paula Correia

Ana-Paula Correia, Ph.D., is a Professor of Learning Technologies and the Director of the Center on Education and Training for Employment at The Ohio State University, Columbus, Ohio, United States. Her research is focused on learning technologies, learning design, human-computer interaction, and artificial intelligence in education and training. Her work has been published in over 100 refereed papers and book chapters.

correia.12@osu.edu
0000-0003-0806-7835
https://www.ana-paulacorreia.com

Open Access (CC BY 4.0)

© 2020 The Authors. This article is distributed under Creative Commons Attribution 4.0 International licence.

You are free to

- Share — copy and redistribute the material in any medium or format
- Adapt — remix, transform, and build upon the material for any purpose, even commercially.

Under the following terms:

- Attribution — You must give appropriate credit, provide a link to the license, and indicate if changes were made. You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.
- No additional restrictions — You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits.

The full licence conditions are available at: **https://creativecommons.org/licenses/by/4.0/**