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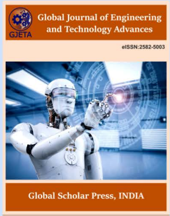

(Review Article)

STEM learning supported by educational chatbots: Cognitive and pedagogical dimensions

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Abstract

The fast evolution of digital technology has drastically changed the face of modern education, especially in the fields of Science, Technology, Engineering, and Mathematics (STEM). Among the new digital tools, educational chatbots stand out as innovative systems that can potentially support students' learning processes through personalized interaction and constant feedback. AI-powered chatbots can offer learners tailored educational experiences which facilitate a deeper comprehension of intricate STEM concepts. The current article investigates the contribution of educational chatbots in STEM learning from both cognitive and pedagogical perspectives. It delves into how learning environments assisted by chatbots can foster better grasp of concepts, sharpen problem-solving skills, enhance metacognitive abilities, and nurture learner self-direction. Moreover, as digital technology has become deeply integrated into contemporary educational environments, this study reflects on the pedagogical ramifications of incorporating chatbots in STEM classrooms, encompassing differentiated instruction, tailored learning pathways, and higher student commitment. In this same light, the article considers the pros and cons of chatbot-augmented STEM learning environments with an emphasis on teachers' roles as technology-enhanced learning facilitators. The results indicate that educational chatbots can serve as capable cognitive support tools that complement traditional teaching methods and make STEM education more inclusive and flexible. Educational chatbots seem to be an attractive option for the next stage of STEM education, especially in digitallyrich learning environments. Their use in the classroom can be a step forward in nurturing 21st-century skills and ensuring that students of various backgrounds have enriching learning experiences.

Keywords: Educational chatbots; STEM education; Digital learning; Artificial intelligence in education; Cognitive support; Personalized learning; Technology-enhanced learning; STEM learning

1. Introduction

Science, Technology, Engineering, and Mathematics (STEM) education has become one of the major focuses of modern education systems worldwide (Margot & Kettler, 2019). The growing technological sophistication of contemporary societies necessitates that individuals acquire not merely advanced technical knowledge but also key higher-order competencies, including critical thinking, problem-solving, creativity, and digital literacy (Van Laar et al., 2017). Thus, STEM education is deemed crucial in equipping students for their roles in knowledge-driven economies and technologically sophisticated societies (Bybee, 2013; Honey et al., 2014).

The advent of digital technology in education has deeply altered the way educators and learners carry out their activities (Simos et al., 2026a). Besides extending learning activities beyond the confinements of the brick-and-mortar classroom, online education allows the designing of new instructional methods that help facilitate learning and student engagement

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(Redecker, 2017; Selwyn, 2016). Moreover, technology-based training sessions provide students with options for playfully discovering materials, getting instant feedback, and using individual learning paths (Henderson et al., 2017). These components play a very important role in STEM education where students' conceptual understanding of the disciplines and their problem-solving skills are at the core of the learning objectives (Hillmayr et al., 2020).

Over the past few years, education-related chatbots have become a notable class of electronic tools for learning. Educational chatbots are a type of software that simulate a human-like conversation for the purpose of facilitating learning through interactive dialogue (Okonkwo & Ade-Ibijola, 2021; Winkler & Söllner, 2018). They give students the possibility to inquire, comprehend the material better, and seek assistance when necessary (Okonkwo & Ade-Ibijola, 2021). Compared to conventional learning resources, chatbots engage one in a conversational manner that can be equated to interaction with a human tutor, thus, potentially increasing the students' drive and focus (Fryer & Carpenter, 2006).

Owing to their potential for advanced and personalized scaffolding of student learning, educational chatbots have increasingly been employed in STEM contexts in recent years (Okonkwo & Ade-Ibijola, 2021). Since STEM subjects deal with a broad range of abstract concepts, multi-step problems, and the necessity to utilize knowledge in unfamiliar situations, chatbots can only be one of the learning tools by providing students with guidance throughout the different stages of problem-solving, clearing up misconceptions, and giving practice exercises that fit individual learning needs (Holmes et al., 2022; Zawacki-Richter et al., 2019).

Studies reveal that chatbots, as learning companions, could facilitate students' STEM knowledge solidification and overall academic improvement in STEM-related subjects (Alemdag, 2025; Laun& Wolff, 2025; Okonkwo & Ade-Ibijola, 2021). Educators are able to leverage chatbots for the benefit of building students' problem-solving competences as well as their metacognitive abilities because of the feature of continuous interaction and instant feedback (Chen et al., 2020; Luckin et al., 2016). Hence, with these characteristics, educational chatbots are highly compatible with personalized learning that allows students to move at their own speed (Okonkwo & Ade-Ibijola, 2021).

One additional significant merit of educational chatbots is their promise to become a tool for attaining inclusive education (Simos & Katsiampoura, 2025). Chatbots are well equipped to deliver individualized assistance to learners with diverse needs and thus, reducing the barriers that separate students from engaging in STEM learning activities (UNESCO, 2021; Drigas & Sideraki, 2024). Through customizing both explanations and activities according to the abilities and preferences of the learners, chatbot-supported settings can advocate for equitable access to education (UNESCO, 2021).

However, along with their many advantages, the application of educational chatbots in STEM teaching has certain flaws. Comprehensive in-service training for teachers is indispensable for effective and disruption-free integration of chatbot technology into instructional practices (Tan et al., 2025). In addition, a key concern involves potential unreliability of the chatbot output and the ethical dilemmas associated to artificial intelligence (AI)use in education (Williamson & Eynon, 2020).

The objective of this paper is to discuss the use of educational chatbots in STEM learning with an emphasis on the cognitive and pedagogical components. The paper seeks to discover in what ways the learning environments supported by chatbots could improve students' grasp of STEM concepts and help educators to excel in their teaching activities. The following parts of the paper will discuss STEM education in the context of digital learning environments, define the features of educational chatbots, reflect upon the cognitive and pedagogical facets of STEM learning, and bring forward the implications foreseen for STEM education of the future.

2. Methodology

This study is built upon a structured literature review which serves as a tool to investigate the role of educational chatbots in STEM learning environments, especially highlighting their cognitive and pedagogical dimensions. Researchers have chosen the literature review method to integrate the research results they came across and to offer a clear picture of chatbot-supported educational settings in Science, Technology, Engineering, and Mathematics education (Snyder, 2019; Zawacki-Richter et al., 2019).

To identify relevant studies, the literature search focused on peer-reviewed publications exploring the implementation of educational chatbots and conversational agents in technology-enhanced and digitally mediated learning environments. Special attention was paid to research that implemented chatbots into the educational context and showed their impact on students' conceptual understanding, problem-solving skills, learning engagement, and self-regulated learning processes (Holmes et al., 2022; Luckin et al., 2016).

The pertinent works were mainly located through the major academic databases, such as Scopus, Web of Science, ERIC, and Google Scholar. The search was limited to studies published from 2010 to 2025 so as to include the latest developments in educational chatbots and digital learning technologies. This time frame corresponds with the fast growth of conversational AI systems and the increasing dependence on them in the educational sector (Okonkwo & Ade-Ibijola, 2021; Winkler & Söllner, 2018).

The selection process began with the screening of the initially identified studies and, after that, the detailed examination of the studies that explored the educational use of chatbots and conversational agents. Non-educational publications were discarded. In total, the final pool consisted of seventy research articles that were recognized as being representative of the field of chatbot-supported learning environments.

The studies which were chosen as the representative sample were subjected to qualitative thematic analysis to capture the main research trends and recurring themes across the literature (Braun & Clarke, 2006). The evaluation of the literature was centered on the role of educational chatbots in STEM learning and their impact on instructional practices in technology-rich educational settings. The major focus was on the cognitive and pedagogical milieus of chatbot learning, including conceptual understanding, knowledge construction, personalized learning, and student engagement (Chen et al., 2020; Drigas & Sideraki, 2024).

This methodology offers a logically grounded review of the literature that explores how the educational chatbots impact STEM education and it is helpful in realizing their educational potential.

3. STEM Learning in Digital Environments

3.1. Digital Technologies in STEM Education

Science, Technology, Engineering, and Mathematics (STEM) education in today's educational systems is the backbone of the ever-changing world,as relentless technological advancements and scientific progress increasingly propel societal transformation and economic development (Bybee, 2013). The main goal of STEM education is to facilitate interdisciplinary knowledge and the development of skills such as critical thinking, problem-solving, and digital literacy that are indispensable for participation in knowledge-based economies (Bybee, 2013; Honey et al., 2014; Kelley & Knowles, 2016). Because of the growing significance of these skills, educational systems all over the world have been putting emphasis on technology integration in the STEM learning environment (Van Laar et al., 2017).

Digital technologies have brought about a dramatic change in how STEM-related knowledge is delivered and acquired (Drigas & Mitsea, 2022; Moraiti et al., 2022; Simos, 2025a). Technology-enriched learning settings grant access to a wider range of interactive and engaging learning experiences that break the boundary of regular classroom lessons (Hillmayr et al., 2020). Digital resources like simulations, virtual labs, multimedia, and interactive learning platforms give students the chance to go deeper into scientific phenomena and mathematical concepts (Galitkaya & Drigas, 2020; Redecker, 2017; Selwyn, 2016). These featuressupport inquiry-based learning approaches and encourage students to actively construct knowledge through experimentation and exploration (Henderson et al., 2017).

Digitally supported STEM learning environments promote student-centered approaches that emphasize active participation and independent learning (Hillmayr et al., 2020). Students use digital tools and online resources to conduct investigations, come up with and try out solutions, and formulate explanations (Henderson et al., 2017). Empirical evidence indicates that such technology-enriched learning environments significantly enhance students' conceptual comprehension of scientific and mathematical principles while promoting the development of higher-order thinking skills (Hsu et al., 2017; Voogt et al., 2015). Student-centered digital learning places greater emphasis on engagement and the act of meaningful learning than the traditional lecture-based instruction (Hillmayr et al., 2020; Margot & Kettler, 2019).

Among the numerous benefits of digital technologies usage in STEM education, one of the most significant ones is that these technological features allow learning to incorporate an instant and ongoing feedback process (Henderson et al., 2017). Feedback is an essential part of the learning process, especially in subjects such as mathematics and science, where students build up both conceptual understanding and procedural knowledge step by step. Immediate feedback makes it possible for a learner to spot his or her mistakes, misconceptions, and misunderstanding that it might correct them, thus paving the way for more refined learning pathways or strategies (Hattie & Timperley, 2007; Shute, 2008).

The digital learning settings facilitate the process of giving feedback by making it automatic and continuous thus allowing for more efficient learning processes (Hillmayr et al., 2020).

In addition to all the above, digital technology help provide personalized learning experiences by permitting students to learn at their own pace, according to their individual needs and different potential, as they foster personalized learning environments that prioritize students' prior knowledge and their learning pace in order to adapt the instructional content and learning activities (Henderson et al., 2017). That kind of flexibility is especially important in STEM education where students typically display a considerable range of abilities in terms of both background knowledge and learning pace (Holmes et al., 2019; Pane et al., 2017). Through personalized learning environments, learners are given the opportunity revise the lessons, redo the exercises, and get extra explanation whenever it is needed.

Moreover, one of the features that set digital learning environments apart is the vastness of learning resources made readily available (Redecker, 2017; Selwyn, 2016). Online educational platforms offer students a vast variety of resources at their disposal such as instructional videos, simulations, digital textbooks, and interactive activities (Hillmayr et al., 2020). These resources give students the possibility to deepen their knowledge by themselves, without a tangible classroom while the access to digital resources makes the learning instructions versatile and gives students the freedom to learn any time they want (Mayer, 2014; Means et al., 2014).

Additionally, technological means enable collaboration in STEM learning through communication platforms and collaborative tools which help students work on shared projects or exchange ideas easily (Henderson et al., 2017; Hillmayr et al., 2020). Collaborative learning has been proven to improve students' understanding of the concepts involved and also foster higher-order thinking skills as a result of encouraging discussion and sharing (Dillenbourg, 1999; Johnson & Johnson, 2009).

Despite the aforementioned benefits of digital technology in STEM education, its utilization in the class should be appropriately planned from the pedagogical perspective in order to reach the desired effect on students learning (Tzagkourni et al., 2021). Teachers are expected to discover and practice the skills through which integrating digital learning resources into their class instructions would be more effective. In case a teacher lacks the sufficient pedagogical knowledge of implementing technology, the digital learning resources would only be utilized in a manner that is superficial and would not lead to any significant increase in the learning outcomes (Ertmer & Ottenbreit-Leftwich, 2010; Tondeur et al., 2017). Hence, successful implementation of technological tools must be done in conjunction with learning goals and content (Hillmayr et al., 2020).

In essence, digital technologies are crucial for the improvement of STEM education in a way that not only help make learning more interactive but also help customize learning as per individual needs while facilitating the construction of knowledge through collaboration (Henderson et al., 2017; Hillmayr et al., 2020). These advancements in digital technologies have laid the foundation for the development of more sophisticated digital instruments such as those supported by AI as well as conversational technologies which will further augment STEM learning spaces (Van Laar et al., 2017).

3.2. Artificial Intelligence and Conversational Technologies in STEM Learning

Progressive innovations Recent advancements in AI have paved the way for delivering personalized and adaptive supportin digital learning environments (Bamicha & Drigas, 2022). The infusion of AI in education is a leading factor in the development of educational technology products, such as smart learning systems, that are capable of offering students individualized educational assistance (Luckin et al., 2016). These systems are able to interpret the learning progression of each student and subsequently decide on the most suitable content and method of teaching, thereby making the educational process more effective and personalized (Holmes et al., 2022; Luckin et al., 2016; Zawacki-Richter et al., 2019).

There are also strong indications that highlight the benefits of AI implementation with in STEM learning environments, which are notorious for their challenging nature (Hillmayr et al., 2020). Among the different manifestations of the use of AI in education, intelligent tutoring systems stand out as the most significant (Holmes et al., 2022; Kulik & Fletcher, 2016; Zawacki-Richter et al., 2019). This kind of systems provides students with guidance, feedback, and support that are tailored to their individual learning needs, which is exactly what an one-to-one tutor would do. Results from the investigations into this issue suggest that the utilization of intelligent tutoring systems leads to substantial enhancements in students' learning and comprehension levels in STEM subjects (VanLehn, 2011; Kulik & Fletcher, 2016).

There is more to AI technologies than just intelligent tutoring systems. For instance, when it comes to adaptive learning solutions, AI enables the creation of truly responsive platforms that can scale their support according to students' needs in real-time (Tan et al., 2025). Such learning systems would intervene by providing students with extra clarifications, more examples or additional exercises whenever they face difficulties. This sort of guidance is instrumental in helping students overcome learning challenges effectively thus resulting in efficient knowledge acquisition (Chen et al., 2020; Holmes et al., 2019).

One of the fastest growing fields within AI-based learning environments is that of conversational technologies (Ganguly et al., 2026). These systems operate by interpreting natural language inputs from users and then generating appropriate responses, typically in the form of speech or text. The essence of learning with conversational systems is that students can treat the digital learning tool as their educational companion or assistant with whom they get to talk just as they would to a human teacher or a peer (Kuhail et al., 2023). Moreover, they can ask questions, request explanations, and receive guidance in an interactive way during the learning process (Winkler & Söllner, 2018).

The level of interaction provided by such technologies is potentially invaluable in STEM education whereby the student is almost always faced with the difficulty of understanding problems that are not straightforward, and which require conceptual understanding, multi-step reasoning and on-demand guidance to clarify misconceptions or seek targeted instruction (Holmes et al., 2022). The availability of the question answering feature is the key to seamless learning, as it also acts as a motivator for students, preventing discouragement during complex and frustrating tasks (Laun, 2025). The synergy of human-like interaction and the beneficial effects of social presence is a powerful tool and therefore the students are further encouraged to adopt the use of conversational technologies and their interventions as part of their learning route (Okonkwo & Ade-Ibijola, 2021).

Furthermore, the use of AI-powered conversational systems in education can be broadly seen as a step toward the creation of more equitable learning settings (Sophos, 2025). The adaptive nature of digital learning resources comes from their ability to recognize individual learners', including those with special educational needs, and to compensate by tailoring instruction based on their unique comprehension level and learning pace (Navas-Bonilla et al., 2025). Needless to say, such environments have the potential to minimize educational disparities hence fostering equal learning opportunities for different groups of students (Drigas & Sideraki, 2024; UNESCO, 2021).

However, AI technologies, while unlocking a great deal of potentials, also present a number of challenges for the educational context (UNESCO, 2021). Human errors, biased datasets, and lack of transparency in algorithmic decision-making are among the concerns raised regarding the accuracy of automated responses, and ethical considerations of AI in education (Porayska-Pomsta et al., 2023). In the learning context, teachers are the gatekeepers and facilitators of students' responsible use of AI-powered tools which, in turn, ensures support for learning that is real and meaningful (Williamson & Eynon, 2020).

The deployment of AI together with the conversational technologies marks a major milestone in digitally supported STEM learning environments evolution. Among the various types of conversational AI, educational chatbots are one of the most breakthrough innovations combining interactive communication with personalized learning support at the same time (Ganguly et al., 2026). The next part looks into the distinction and functions of educational chatbots in STEM learning environments.

4. Educational Chatbots in STEM Learning

4.1. Characteristics of Educational Chatbots

An educational chatbot is one of the most up-to-date innovations in digitally supported learning environments, as they are conversational systems that simulate human interaction and support learning through dialogue-based communication (Ganguly et al., 2026). They let learners ask questions, receive explanations and get guidance just like they would if they were interacting with a human tutor (Okonkwo & Ade-Ibijola, 2021; Winkler & Söllner, 2018).Educational chatbots usually rely on natural language processing technologies that allow users to talk to computer systems in natural, everyday language (Ganguly et al., 2026). Being able to use natural language makes the use of technology less complicated and learners stay focused on understanding the content of the course rather than figuring out how to use technological tools (Fryer & Carpenter, 2006; Dale, 2016). Thanks to this feature, educational chatbots are seen as especially suitable for learning settings, where students need continuous guidance and support.

One major factor that sets educational chatbots apart from other kinds of digital instructional tools is their ability to instantly reply to a student query (Okonkwo & Ade-Ibijola, 2021). Prompt feedback is important for successful learning, especially in STEM fields where students can have trouble with problem-solving or grasping abstract concepts (Sofroniou et al., 2025). Chatbots provide explanations and clues that support students so as they solve their inquiries and thus continue learning without any disruption (Shute, 2008; VanLehn, 2011).

Another major feature of educational chatbots that deserves mentioning is that they foster personalized learning as they can tailor their answers to individual students by changing the kind of explanations, or examples shown based on the needs of students(Okonkwo & Ade-Ibijola, 2021; Kuhail et al., 2023). Personalized learning settings make it possible for students to move on at their own pace and get extra help when needed (Luckin et al., 2016; Holmes et al., 2019).

Educational chatbots may also be used as virtual tutors for students (Okonkwo & Ade-Ibijola, 2021). Virtual tutoring platforms present the learning materials and also elaborate on the steps involved in problem-solving while providing further examples (Laun, 2025). Virtual tutoring plays a particularly important role in STEM education, where students have to be guided in the practical application of the concepts (Kulik & Fletcher, 2016).

Besides assisting individual learning, educational chatbots can improve the students' motivation as well as engagement (Heung& Chiu, 2025). The interaction through conversation makes the students feel that the learning experience is more interactive and responsive as compared to traditional digital learning materials (Huang et al., 2025). Students usually attribute chatbot-enabled learning to be more engaging, as it demands active participation and ongoing interaction, fostering a sense of dialogue and immediacy that enhances motivation and sustained involvement (Fryer et al., 2017; Smutny & Schreiberova, 2020).

Educational chatbots can make a positive contribution to an inclusive learning environment by offering personalized support to students with various learning needs (Pergantis et al., 2025). Educational chatbots can change the format of the presentation of information as well as allow for repeated explanations when needed. Such flexibility remains a great aid for learners who might only be experiencing problems with the traditional classroom environment and also helps to ensure equal opportunities in STEM learning (UNESCO, 2021; Drigas & Sideraki, 2024).

Educational chatbots, like any other tool, aren't perfect. Chatbots may sometimes provide responses that are incomplete or inaccurate, especially when the questions are complex or ambiguous (Laun, 2025). Therefore, chatbots should be seen as a supplemental learning tool and not as a replacement for teachers (Williamson & Eynon, 2020). Teachers are the ones who decide the course of learning and ensure that the learning content provided is accurate (Holmes et al., 2022; Williamson & Eynon, 2020).

In sum, educational chatbots signify a versatile, interactive form of digital learning support with the potential of enriching STEM learning environments. The conversational nature of these chatbots and their readiness to support each student according to their individual learning needs makes them a good partner for learners when tackling challenging tasks.

4.2. Chatbots’ Applications in STEM Education

The use of educational chatbots in STEM education is gaining momentum as one of the ways to help students learn scientific and mathematical concepts. To master STEM-related notions, learners need to be able to think deeply and apply their knowledge in different situations. Chatbots can be instrumental in turning these demands into manageable tasks by providing students with explanations, giving examples, and letting them have guided practices that suit their level of understanding (Zawacki-Richter et al., 2019; Holmes et al., 2022).

When used in mathematics instruction, chatbots provide help to students as they break down a problem into smaller, manageable parts and explain them step-by-step, thereby scaffolding the problem-solving process and promoting deeper conceptual understanding (Turmuzi, 2026). Students can consult a chatbot for questions on mathematical procedures and receive instant evaluation of their solutions, enabling immediate feedback that helps identify errors, refine strategies, and reinforce learning in real time (Laun, 2025).This kind of support is very helpful in that it enables the student to develop problem-solving techniques and gain a better grasp of the mathematical concepts being studied (VanLehn, 2011; Kulik & Fletcher, 2016). Chatbots have also been integrated into science teaching in a way that they help students grasp the scientific concepts, principles and the nature of science altogether. Students are at liberty to pose questions about things that happen in our universe and the chatbot offers answers that connect the students' theoretical knowledge with practical/scientific applications (Chen et al., 2020).Similarly, they can be of great assistance for students learning programming as they provide solutions to coding problems or technical issues. Students can use chatbots as an aid when writing computer programs and finding errors that they have made (Deng et al., 2025). Such support gives learners the confidence and means to carry on their learning independently, while also lessening the frustration that is associated with the behavior of computer programs (Winkler & Söllner, 2018).

Educational chatbots can also extend their support to students beyond the classroom. A large number of chatbot-based solutions might be reached through internet portals or mobile devices (Stathopoulou et al., 2018; Simos, 2025b). In that way, one can be engaged in learning whenever, and wherever they like. Learning thatbecomes independent of time and place makes it possible for the students to work on, practice and review what they have learnt (Means et al., 2014; Holmes et al., 2019).

Furthermore, educational chatbots can effectively support diverse learners in STEM education by delivering highly individualized experiences that allow students to progress at their own pace (Okonkwo & Ade-Ibijola, 2021). This personalized approach helps bridge existing learning gaps, particularly among students with varying levels of prior preparation, interest, or ability, while promoting more equitable access to challenging STEM content (UNESCO, 2021). Moreover, such adaptive support proves especially valuable in inclusive educational programs, where accommodating diverse needs is essential for fostering participation and success for all learners (Pane et al., 2017; Drigas&Sideraki, 2024).

According to research, students' use of chatbot-supported STEM-related learning environments could lead to them being more engaged and more active learners (Laun, 2025). Specifically, pupils who are given conversational learning tools usually have more opportunities to get involved in learning activities because they can raise questions without hesitation and get answers promptly (Huang et al., 2025). The higher level of student-teacher interaction in these learning environments results in greater student comprehension and even more learning that is meaningful (Okonkwo & Ade-Ibijola, 2021; Smutny &Schreiberova, 2020).

Hence, educational chatbots work well as a major instrument in assisting STEM learning that takes place in various subjects, levels and teaching contexts. Firstly, they can offer guidance easily with little interruption and secondly, they are good at giving feedback according to each learner's needs, thus making them quite valuable in digitally supported learning environments. The next part digs deeper into the cognitive and pedagogical issues related to chatbot-mediated STEM learning.

5. Cognitive and Pedagogical Dimensions of Chatbot-Supported STEM Learning

5.1. Cognitive Dimensions of Chatbot-Supported STEM Learning

Educational chatbots might significantly impact students' cognitive development in STEM learning environments, as they demand the development of higher-order cognitive skills such as conceptual understanding, critical and analytical thinking, and problem-solving skills (Wang & Fan, 2025). Chatbots can foster the growth of these skills by offering the learners structured help and instant feedback throughout the learning journey (Luckin et al., 2016; Holmes et al., 2022).

One major cognitive advantage that comes with chatbot-assisted learning is conceptual understanding(Laun, 2025). Very often students have a hard time grasping abstract concepts of science and math. Educational chatbots may facilitate conceptual understanding by the provision of simple language explanations and the supply of new examples, thus assisting students in associating the new knowledge with the old one (Mayer, 2014; Chen et al., 2020). Repeated use of chatbot programs enables students to progressively deepen their understanding and eliminate errors in their thinking (Laun, 2025).In this same light, chatbot-supported learning environments may also foster the development of student's problem-solving abilities. It is natural that STEM students have to concentrate on finding solutions to complex problems involving several layers and reasoning in the domain (Wang & Fan, 2025). A chatbot may be a student's guide and help through problem-solving procedures by providing hints and explaining each step. Such a method of teaching fosters students' creation of a methodical problem-solving approach, enabling them to reinforce their knowledge and apply it to different situations (VanLehn, 2011; Kulik & Fletcher, 2016).

Metacognition is yet another vital cognitive aspect of chatbot-supported learning (Drigas&Mitsea, 2022). Metacognition is about learners' ability to oversee and adjust their learning activities. Chatbots might be a great aid to developing metacognitive skills since they might prompt students to look over their responses and even consider other problem-solving tactics (Simos et al., 2026b). As a result of the interaction with a chatbot, a learner's self-awareness of the progress becomes clearer presumably leads to more effective study methods (Azevedo &Aleven, 2013).Additionally, educational chatbots might be used as a tool to help learners construct knowledge by engaging actively with the learning content. Theories of constructivist learning strongly advocate learners' active involvement in the learning process and emphasize the interaction as a crucial factor in knowledge development (Bruner, 1966; Vygotsky, 1978). Thus, environments supported by chatbots can inspire learners to question and investigate new concepts actively, thus facilitating profound learning.

Moreover, scaffolding is a cognitive function provided by chatbots, which can help educators provide step-by-step instructions whilecontinuously modifying the challenge level and also giving students' tips that are at the same level as their current ability (Wang & Fan, 2025). This adaptive scaffolding supports the students' learning journey from initial concept recognition through to advanced mastery, making progressive knowledge construction more accessible, structured, and effective in STEM contexts(Wood et al., 1976).

The findings also point out that a chatbot-based learning environment could enhance students' focus and attention during learning exercises. Communication through a conversation necessitates active involvement and stimulates the learner to stay devoted. Hence, the concentration that is maintained results in the achievement of the set goals and facilitates deeper comprehension of the STEM concepts (Smutny &Schreiberova, 2020).

In brief, chatbot-assisted learning environments do provide support in various areas such as the understanding of concepts through problem solving, raising awareness of one's thinking process, and building new knowledge in STEM education. These cognitive advantages justify why educational chatbots are considered helpful learning devices in complicated tasks.

5.2. Pedagogical Dimensions of Chatbot-Supported STEM Learning

Along with cognitive benefits, educational chatbots have critical pedagogical implications in the field of STEM education. By adopting chatbot technologies, educators can facilitate innovative teaching methods and provide a more flexible as well as inclusive learning environment (Holmes et al., 2019; Simos &Katsinis, 2026; Zawacki-Richter et al., 2019).

Furthermore, one pedagogical benefit that has been widely recognized in recent literature is the personalization of learning supported by chatbots (Kuhail et al., 2023; Laun, 2025;Okonkwo & Ade-Ibijola, 2021). In a standard classroom, it is very challenging for teachers to attend to the individual needs of every student, and thus educational chatbots hold the promise of individualized support through explanations and exercises tailored to students' abilities (Laun, 2025). Such individualized learning gives students the freedom to learn at their own pace and also are provided support when they need it (Pane et al., 2017).

With the help of educational chatbots, teachers can also provide differentiated instruction by using various explanations and learning activities (Nguyen & Nguyen, 2025). Differentiated instruction is a known teaching strategy that involves adjusting the content, process, products, and the learning environment to cater to the diverse learning needs of students (Simos, 2025c). Therefore, chatbots can not only be used to present contents at variable levels of difficulty but also introduce extra scaffolding to the students who require it (Tomlinson, 2014).

Additional to the above is another significant pedagogical aspect of chatbot-supported learning which is its immense power regarding increasing student engagement (Huang et al., 2025; Laun, 2025). Engagement is one of the critical elements determining the success of learning in STEM education and therefore the dialogue element of chatbots can enhance students' interest in learning as it maximizes interactivity and responsiveness(Cao et al., 2025). Learners generally find chatbot-supported learning more engaging than traditional methods (Fryer et al., 2017).

Apart from these pedagogical functionalities, chatbots are also capable of addressing the issue of flexibility in learning environments because students can get access to learning assistance at any time (Laun, 2025). Many chatbot-based systems are accessible via the Internet and mobile devices, which means that learners may get help even when they are not in class (Chaidi &Drigas, 2022). Having any kind of supportavailable, anytime and anywhere, encourages self-directed learning and helps to develop learner autonomy (Means et al., 2014).

Also, chatbot-based learning environments are capable of being inclusive ones (Fitas, 2025). As inclusive education is a philosophy and practice that guarantees the students of all abilities and disabilities learn together in the same age-appropriate class and community, educational chatbots can deliver personalized instructions and additional practice for students with special needs (UNESCO, 2021). So, providing adaptive support will not only remove barriers to learning but will also make it easier for students with different needs to participate in STEM activities (UNESCO, 2021; Drigas&Sideraki, 2024).

Despite having many advantages, educators should consider carefully how to implement the use of educational chatbots in their classes. There is no doubt that teachers are indispensable if students are to use chatbot technologies effectively and in an educationally beneficial way, as they need to oversee the entire learning activity to make sure it adheres to the set goals(UNESCO, 2021). Hence, the use of chatbots should only be regarded as a tool in the teacher's toolbox and not considered as a teacher's replacement (Williamson & Eynon, 2020).

Educators' use of chatbots can be their greatest trait when they are used as a mixture of individualized learning support and interactive communication. Thus, if teachers integrate chatbots effectively into their teaching practices, the chatbots might bring about more personalized, engaging, and inclusive STEM learning experiences.

6. Discussion

The current research explored the function of educational chatbots in STEM learning settingsand focused mainly on their cognitive and teaching aspects. The outcomes of the literature review suggest that educational chatbots are a significant innovation in digitally mediated educational settings and thus, they have a great potential to enhance STEM education. The incorporation of conversational technologies in educational settings opens new possibilities for supporting students' comprehension of difficult concepts and further improving their educational experiences.

The literature review reveals that educational chatbots may serve as very useful cognitive scaffolding devices in the learning process of STEM disciplines (Simos et al., 2026a). Learners who studytheoretically in chatbot-assisted environments are provided with help and explanations at all times, which supports both concept acquisition and problem-solving skills. Also, the students' mistake recognition and knowledge revision become more efficient through immediate feedback. These results match the findings of earlier studies that underline the need for interactive educational environments as a prerequisite for cognitive growth (Luckin et al., 2016; Holmes et al., 2022).

Apart from this, the current research points out the close relationship between educational chatbots and personalized learning. With the help of chatbots, learners are free to move onward with their studies following their own speed and pace while receiving any extra help if they need it. Personalized learning environments are thus considered crucial in STEM education since researchers have shown that most students vary considerably in their previous knowledge and learning capabilities. The chatbot's flexibility feature enables a learner to get one-on-one support that is a perfect fit for the rest of the instruction (Pane et al., 2017; Holmes et al., 2019).

The current research, in particular, points out that educational chatbots can be utilized to support differentiated instruction by offering multiple explanations of the same concept and alternative learning paths based on the students' preferences and needs. Moreover, studies showed that chatbot interaction can positively influence students' motivation and engagement by bringing interactive elements to learning activities. These refer to the increase of the students' engagement, which is one of the components linked to better learning outcomes and deeper conceptual understanding in STEM education (Fryer et al., 2017; Smutny &Schreiberova, 2020).

Other than the differentiated elements of instruction, educational chatbots are in fact closely related to the idea of creating inclusive learning environments. What may still be an issue is the fact that some learning barriers can only be lessened to a certain extent through technology, as human support cannot be completely substituted by machines. Even so, technology can be a complementary device that facilitates the activity of accessing information or carrying out learning tasks, thus helping to make learning opportunities more equal. Based on these findings, it seems like chatbot-supported learning environments could act as one of the major contributors to making STEM education more accessible to all students (UNESCO, 2021; Drigas&Sideraki, 2024).

Even though they have a great potential, educational chatbots also have some important limitations. One major concern is that chatbot-generated responses might not always be accurate and reliable (Laun, 2025). When switched to answer highly complicated questions, conversational systems might be prone to giving incomplete or wrong information. Therefore, the use of chatbot-supported learning environments has to be done with utmost caution and teachers should still take the role of supervisors and guides. Teachers' intervention is a key factor in ensuring that the learning process is of high quality and accurate (Williamson & Eynon, 2020).

Hence, the effective integration of chatbot technologies in education is brought into question. To be successful with the implementation, appropriate pedagogical planning as well as adequate teacher training should be considered. A teacher should be able to incorporate chatbot-mediated tasks into their teaching in a way that makes sense and adds value. When teachers lack the skills needed for sound instructional design, the chances are very high that the advantages brought by chatbot technologies remain at an unrealized potential (Tondeur et al., 2017).

7. Conclusions

The current study adds to the existing evidence of research on the use of conversational technologies in education. It aims to provide a well-rounded review of the different ways educational chatbots can help STEM learning by emphasizing the cognitive and pedagogical aspects. The studyprovides information that reveals that chatbot-led education is capable of simultaneously enhancing conventional teaching methods and facilitating more adaptable and personalized modes of learning.

There is a need for a deeper exploration of how effective educational chatbots are when used in actual classrooms. In particular, empirical research that monitors the change in students' learning outcomes and engagement levels in chess-standard bot-assisted STEM classes could offer very useful insights on the practical educational values of conversational technologies. Some other areas that are worthwhile considering by future researchers might include examining the long-term effects of chatbot learning facilitation in terms of students' cognitive growth and academic success.

In a nutshell, educational chatbots represent an innovative means in the realm of digitally mediated STEM education. The fact that they can offer two-way communication as well as one-on-one help makes them fit well for the support of complex learning pathways. If blended with the teaching practices in a right way, educational chatbots can be a great tool in the creation of more effective, stimulating, and inclusive STEM learning milieus. Future research should further investigate the empirical impact of chatbot-supported STEM learning environments in real classroom contexts.

Compliance with ethical standards

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Disclosure of conflict of interest

The Authors proclaim no conflict of interest.

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