Online Journal of Communication and Media Technologies, 2026, **16**(4), e202646
e-ISSN: 1986-3497

OPEN ACCESS

Review Article

The role of information and communication technology in higher STEM education: A systematic review

Elena M. Ibragimova [1*]
0000-0001-9271-0170

Vagiz G. Gimaliev [2]
0000-0003-2758-6972

Ludmila Y. Grebenshchikova [3]
0000-0003-2815-1882

Natalia A. Zaitseva [4]
0000-0002-0048-5509

Elena Zubko [5]
0000-0002-1501-1859

Sergey V. Kondrashev [5]
0000-0002-6547-865X

[1] Kazan (Volga region) Federal University, Kazan, RUSSIA
[2] Chuvash State University, Cheboksary, RUSSIA
[3] Tver State Medical University, Tver, RUSSIA
[4] Plekhanov Russian University of Economics, Moscow, RUSSIA
[5] Sechenov First Moscow State Medical University, Moscow, RUSSIA
[*] Corresponding author: timop2001@mail.ru

Citation: Ibragimova, E. M., Gimaliev, V. G., & Grebenshchikova, L. Y., Zaitseva, N. A., Zubko, E., & Kondrashev, S. V. (2026). The role of information and communication technology in higher STEM education: A systematic review. *Online Journal of Communication and Media Technologies, 16*(4), Article e202646. https://doi.org/10.30935/ojcmt/19267

ARTICLE INFO

Received: 23 Mar 2026

Accepted: 26 Aug 2026

ABSTRACT

The use of information and communication technology (ICT) tools is important in STEM education to enhance student engagement and improve learning outcomes. Despite the importance of ICT in STEM education, no study has analyzed studies conducted on ICT in higher STEM education. Hence, the purpose of this study is to systematically review Scopus-indexed empirical studies to examine how ICT is used, perceived, and evaluated in higher STEM education contexts, including undergraduate students and preservice teachers. Following the PRISMA protocol, we searched the Scopus database for articles published between 2009 and 2025 and applied predefined inclusion and exclusion criteria to screen the retrieved records. This process yielded 12 eligible articles for data analysis; although this number is relatively small, it reflects the outcome of applying strict eligibility criteria to an initial pool of 82 records and allowed an in-depth thematic synthesis rather than a broad overview. Using an inductive thematic analysis approach, we identified five interrelated themes regarding ICT tools in higher STEM education: contributions to skill development, impact on gender, impact on student performance and academic achievement, perception and use, and ICT resources and infrastructure. Together, these themes point to ICT's dual role as both an enabler of learning outcomes and a resource-dependent practice, with several challenges to effective integration also identified across the reviewed studies. Based on these findings, the study offers targeted recommendations for educational policy and practice, along with directions for future research on ICT tools in higher STEM education.

Keywords: information and communication technology, ICT, STEM education, higher STEM education, systematic review

INTRODUCTION

Information and communication technology (ICT) refers to digital tools and platforms including computers, mobile devices, and augmented/virtual reality applications that support instruction (Anastasopoulou et al., 2024); in higher STEM education specifically, these tools have become central to how undergraduate students, preservice teachers, and instructors engage with complex scientific content. Previous research has shown that ICT can positively change the way STEM subjects are taught and learned. For example, computer simulations and animations can help students better understand and retain difficult scientific ideas (Beichumila et al., 2022; Rutten et al., 2012). Students can learn concepts and topics via ICT that are difficult to comprehend in a regular classroom (Beichumila et al., 2022). The use of ICT tools makes it easier for students at any level to access a variety of resources and learning materials (Basargekar & Singhavi, 2017; Navarro-Ibarra et al., 2023). Additionally, ICT can provide students with improved access to education and facilitate collaborative learning in science education contexts (Sasota et al., 2021; Zakaria & Khalid, 2016). Therefore, researchers widely agree that the use of ICT helps students learn, stay interested and motivated, and improve their achievement and other learning outcomes in STEM teaching (Aboderin & Bamisile, 2021; Bandoh et al., 2024; Pham et al., 2025).

Building on this evidence base, research further indicates that ICT use fosters learner autonomy by allowing students to take an active role in their own education (Bandoh et al., 2024), extending the benefits noted above from access and motivation toward self-directed engagement. In particular, Beichumila et al. (2022) suggest that computer simulations and animations can be a useful substitute for experiments that would be dangerous or impossible to perform in a regular laboratory. ICT, therefore, helps to address the lack of resources for instructors and learners. The findings of Saltan et al. (2018) emphasize that the use of educational technologies in STEM education helps students to achieve clear learning objectives and improve their understanding of science classes, concepts, and topics (Saltan et al., 2018). On another point, this ensures learning materials are accessible to everyone, allowing all students to learn science in a meaningful way (Liang et al., 2022).

In addition to these considerations, researchers have documented challenges associated with the implementation of ICT in science education. Studies show that educators face difficulties in using ICT due to insufficient resources or a lack of training (Msambwa et al., 2023). Furthermore, these challenges emphasize the need for careful planning and a well-defined pedagogical framework (Kewalramani & Havu-Nuutinen, 2019). Beyond resource and training constraints, infrastructural barriers such as unreliable internet connectivity and outdated hardware continue to restrict ICT adoption in many higher education contexts, particularly in institutions with limited technology budgets. In addition, disparities in instructors' and students' digital literacy levels can undermine the effectiveness of ICT integration even where infrastructure is adequate (Msambwa & Daniel, 2024).

Although ICT is important in science education for educators and researchers, few review studies have examined the findings of articles on the implementation and use of ICT in science topics, and the ones that do exist tend to focus on different educational levels. Msafiri et al. (2023) analyzed 51 publications on the impact of ICT integration on the teaching and learning process and reported benefits such as equitable access, shared learning resources, and personalized learning, along with challenges related to professional development, pedagogical and technological knowledge, and resource maintenance. A similar set of challenges was reported by Msambwa et al. (2024), who reviewed 54 articles published between 2008 and 2023 using the Web of Science, PubMed, Scopus, and ERIC databases to examine the effective integration of ICT tools in secondary education. Their study also pointed to professional development and skill-building needs and emphasized the role of policymakers in creating an innovative and supportive school environment, as well as the responsibility of school leaders in ensuring that ICT tools remain available, accessible, reliable, compatible, and secure. At the preschool level, Alzahrani (2025) reviewed 23 studies published between 2000 and 2024 across four databases and found that most preschool teachers believed ICT, including augmented reality, had real potential to improve their students' learning; some teachers achieved this successfully even when facing implementation challenges. Her review also suggested that ICT use, including AR, was associated with improved understanding of science concepts and social communication in young children. Focusing specifically on chemistry education, Bellou et al. (2018) reviewed 43 peer-reviewed articles published between

2002 and 2016 and found that ICT was mostly used to help students visualize and model the particulate nature of matter, mainly through multimedia tools and simulations. Across these studies, then, the review literature on ICT mainly covers secondary education (Msambwa et al., 2024), preschool education (Alzahrani, 2025), or a single subject area like chemistry (Bellou et al., 2018), while Msafiri et al.'s (2023) review remains broad in scope without targeting a specific educational level. What is missing from this body of work is any review that looks specifically at higher STEM education, even though the same issues these studies raise, such as resource maintenance, professional development, and equitable access, are just as relevant for undergraduate students and preservice teachers.

Msambwa and Daniel (2024) systematically reviewed the literature on the use of ICT in secondary schools and aimed to determine its effects on learning outcomes and learners. They analyzed 40 eligible studies from the Scopus and ERIC databases. Their findings revealed that effective ICT integration depends on students' and teachers' motivation and attitude change. Furthermore, they proposed that there is a need to develop the maintenance of ICT tools and the appropriate development of ICT skills for both learners and teachers. In summary, these studies reveal that the effective integration of ICT in education has a positive impact on teaching and learning processes, particularly in terms of supporting personalized learning, access to resources, and collaboration. However, what is missing from earlier studies is that there is a lack of studies examining the research results of ICT publications in higher STEM education. Despite the importance of ICT in STEM education, no study has analyzed studies conducted on ICT in higher STEM education. Because of this reason, this study aims to systematically review Scopus-indexed empirical studies published between 2009 and 2025 to examine how ICT is used, perceived, and evaluated in higher STEM education contexts, including undergraduate students and preservice teachers, in order to synthesize the existing evidence and identify directions for future research and practice.

METHOD

In this study, we analyzed articles on the use of ICT in STEM education in higher education using the systematic review method. This method is commonly used by researchers in comprehensive reviews focusing on a specific research topic. Khan et al. (2003) identified the stages of the systematic literature review, including

(a) defining the research question,

(b) identifying studies related to the research question,

(c) summarizing the findings, and

(d) interpreting and discussing the findings.

In this study, we followed the steps proposed by Khan et al. (2003). In this context, we chose articles published between 2009 and 2024 on STEM education and ICT in the SCOPUS database to answer our research question. Since this study compiles existing literature, our study did not require ethical approval from the authors' institutions.

Inclusion and Exclusion Criteria

For studies in this review, we determined inclusion and exclusion criteria. Accordingly, they must

(a) be published articles on STEM education,

(b) be published articles on ICT,

(c) be conducted on participants in higher education,

(d) be published in English, and

(e) present quantitative, qualitative, or method-based findings.

Based on the literature review conducted, we excluded publications unrelated to STEM education and studies written in a language other than English. As a result of the screening, we determined that 12 studies were identified. During data collection, we excluded 15 studies because they did not meet the criteria mentioned above.

Table 1. Inclusion and exclusion criteria used for data collection

Inclusion criteria	Exclusion criteria
Studies have empirical evidence concerning ICT	Studies that did not meet the inclusion criteria
Studies conducted on ICT and higher education	Studies that contained no empirical evidence
Studies published from 2009 to 2024	Studies published before 2009 and published in 2025
Studies written in English	Studies not written in English
Age group must be undergraduate and graduate students	Studies included participants in preschool, elementary, middle, and high school participants

Table 2. An outline of the search in the database

Variable	Value
Time span	2009-2024
STEM education	Science education, biology education, chemistry education, physics education, and STEM education
ICT	ICT, information and communication technology, ICT integration, ICT integration challenges, and factors affecting ICT integration
Higher education	University students, undergraduate students, college students, preservice teachers, and preservice teacher education
Publication year	2009-2024
Publication type	Journal
Document type	Article
Document language	English

In this study, the PRISMA framework (Page et al., 2021) was adopted for data collection and analysis. Thus, a total of 12 articles were included in the final research dataset. **Table 1** shows the detailed inclusion and exclusion criteria to determine the articles that we applied in the study.

Although the inclusion criteria specified undergraduate and graduate student populations, the final set of eligible studies predominantly involved undergraduate students and preservice teachers; no study focusing exclusively on graduate-level participants met the eligibility criteria. Duplicate records retrieved across the search were identified and removed prior to title-and-abstract screening. A formal methodological quality-appraisal tool was not applied in this review; this is acknowledged as a limitation below.

Data Collection

This study relied exclusively on the Scopus database because of its broad multidisciplinary coverage of peer-reviewed education and STEM research and its established use in prior systematic reviews on ICT integration (e.g., Msambwa & Daniel, 2024). Therefore, the Scopus database, which is easy to use and has a wide content network, was selected for this research. For data collection, we searched for documents that were published in journals that were indexed in the SCOPUS database. The search was conducted using the Boolean string *[("STEM education" OR "science education" OR "biology education" OR "chemistry education" OR "physics education") AND ("ICT" OR "information and communication technology" OR "ICT integration") AND ("higher education" OR "undergraduate students" OR "university students" OR "preservice teachers")]*, applied to the title, abstract, and keyword fields, as detailed in **Table 2**. **Table 2** shows a detailed list of keywords we used during the search in the database.

Regarding exclusion criteria, since the type of study to be examined in this research is "article," book chapters, conference papers, etc., which are not articles, have been removed from the dataset. Additionally, only one non-English working article was excluded from the study. Finally, we included 12 articles for analysis in this research. For main keywords, including STEM education and ICT, we used search terms in the keywords. For keywords regarding higher education, we did a search in title-abstract-keywords. As a result of our initial search, thus, we reached a total of 82 studies in the database. The data was collected in July 2025.

Figure 1 shows the PRISMA flow diagram results for data collection in this research. In the initial search, we reached 82 articles in the SCOPUS database. Later, we limited the search to publications in the English language, and the number of documents decreased to 81. After this, we used a filter option to obtain articles published in the database, and the number of articles decreased to 27. Later, two researchers read 27 articles to verify their eligibility for analysis. Thus, we excluded 15 articles from the data, and finally, the number of eligible articles was reduced to 12.

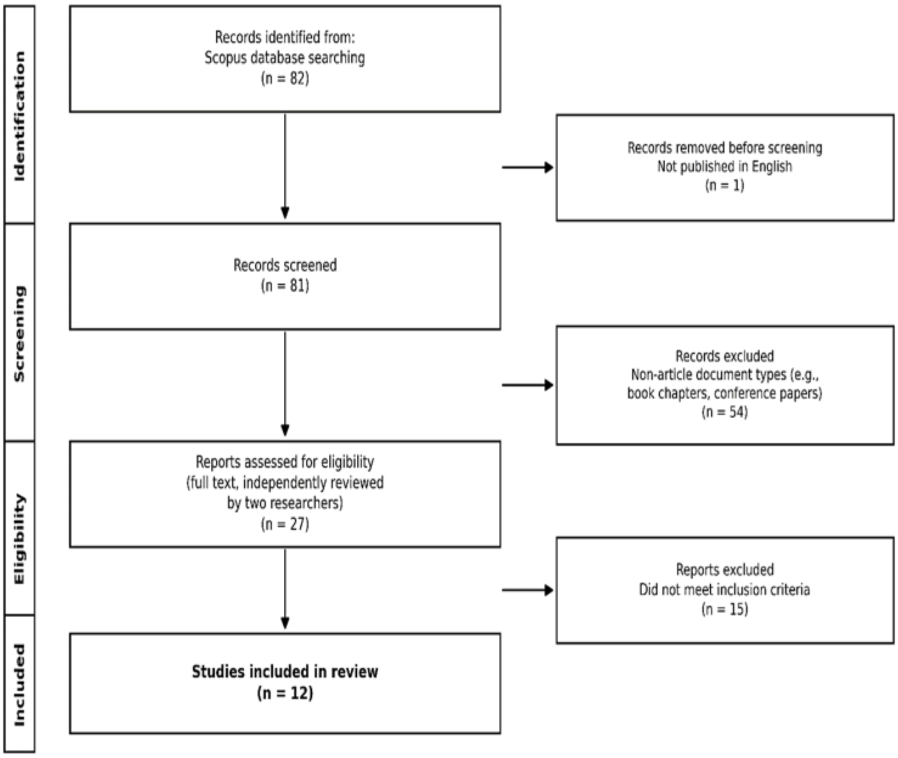

Figure 1. The PRISMA flow diagram (the authors' own elaboration)

The 15 papers we excluded did address ICT tools in higher education contexts. Thus, the systematic review in this study included 12 articles as a result of the final search. Full detailed information concerning all of these studies is presented in **Table 2**.

Data Analysis

A systematic literature review method was used to examine published studies on the use of ICT in science classes for this study. A systematic literature review is defined as locating published research on a given subject and then critically examining it. For this purpose, the eligible articles were analyzed independently by two researchers in light of criteria that had been determined before data analysis began. Specifically, an inductive thematic analysis approach was adopted (Braun & Clarke, 2006), in which codes and themes were derived directly from the content of the reviewed studies rather than from a predetermined theoretical framework. Each article was first read in full, and initial codes were generated based on the reported purposes, findings, and outcomes related to ICT use; these codes were then grouped into broader candidate themes through repeated comparison across the reviewed studies. Once the independent analyses were completed, the two researchers' coding and thematic groupings were compared, and a common view of the analysis of the reviewed studies was reached. When a conflict in data analysis arose, the analyses were discussed by the researchers until a consensus was reached. Regarding reliability, a 92% consensus in the analysis between the two researchers was revealed by the results.

RESULTS

Descriptive Statistics

Figure 2 presents the distribution of the 12 reviewed studies by publication year, ranging from 2010 to 2024. Although publication frequency fluctuated across the period, no clear increasing trend is evident; two studies were published in each of 2020 and 2021, while no studies were retrieved for 2011, 2012, 2017, or 2022. These gaps may reflect the relatively narrow research attention given specifically to ICT in higher STEM education during those years, rather than an actual decline in ICT adoption more broadly.

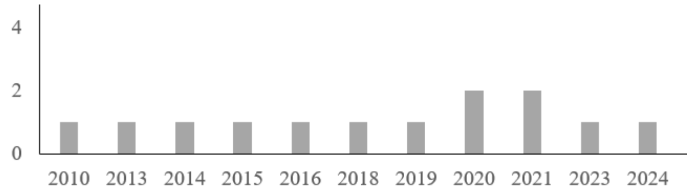

Figure 2. Article distribution per year (the authors' own elaboration)

Descriptive Information

All the participants in the paper were undergraduate students. We found that studies were conducted in Australia, Chile, Israel, Italy, Kenya, Nigeria, Spain, and Turkey. In 66.6% of the studies, researchers (Alonso et al., 2021; Al-Shwabkah et al., 2016; Faenza et al., 2021; Gómez-Espina et al., 2019; Kadıoğlu-Akbulut et al., 2023; Martínez-Cerdá et al., 2018a, 2018b; Schettini et al., 2020) used quantitative methods, 25% were qualitative (Arenas, 2015; Makori et al., 2013; Sobowale et al., 2024), and 8% (Barak, 2013) were mixed methods. In 25% of the studies, participants were preservice teachers (e.g., Barak, 2013; Kadıoğlu-Akbulut et al., 2023; Sobowale et al., 2024). In the other 75%, participants were undergraduate students (e.g., Al-Shwabkah et al., 2016; Faenza et al., 2021; Martínez-Cerdá et al., 2018b) in other disciplines of STEM areas.

Regarding data collection tools researchers used in ICT research in higher STEM education: Six studies (Alonso et al., 2021; Al-Shwabkah et al., 2016; Faenza et al., 2021; Kadıoğlu-Akbulut et al., 2023; Martínez-Cerdá et al., 2018a, 2018b) used surveys for data collection. Two studies used interviews (Arenas, 2015; Makori et al., 2013). Concerning the implementation of ICT applications, one research by Gómez-Espina et al. (2019) used mobile devices, including laptops, smartphones, and tablets. In one research, Arenas (2015) used a simulation tool that included the use of an electronic diary and a discussion forum. In other studies, Schettini et al. (2020) used blended learning, while Sobowale et al. (2024) used an experimental study (see **Table 3**).

Table 3. An outline of selected studies on ICT and higher STEM education

Study	Participants	Country	Purpose	Methodology, study design	Significant results
Alonso et al. (2021)	171 undergraduate students	Spain	Aimed to investigate the motivations of girls to choose computer engineering.	Quantitative, survey	It was found that there were gender significant differences concerning goals and degree preferences.
Al-Shwabkah et al. (2016)	220 undergraduate students	Jordan	To explore undergraduate students' perceptions of ICT and examine the effects of gender, the type of university, academic year and student GPA on and their students' views.	Quantitative, survey	Participants stressed the importance of incorporating ICT courses in LIS programs and found that the other factors (gender, academic year, and GPA) did not appear to affect student perceptions.
Arenas (2015)	18 undergraduate students	Australia	To determined undergraduate students' preferences for ICT media in their learning activities.	Qualitative, interviews, and observations	The most of participants perceived the integration of ICT into learning activities as useful, convenient, flexible, encouraging reflection and good for knowledge sharing and asynchronous interactions.
Barak (2013)	103 preservice STEM teachers	Israel	examine pre- service STEM teachers' attitudes and perceptions about the effectiveness of the use of ICTs	Mixed	The participants' attitudes and their perceptions revealed a gap between their inclination to coincide with educational trends, and their actual views about the use of ICTs and they perceived them as instrumental for leveraging progressive education.
Gómez-Espina et al. (2019)	128 undergraduate students	Chile	To compare traditional approaches and active approaches based on ICT	Quantitative, mobile devices	An improvement in academic performance compared to traditional methodologies,

Table 3 (Continued).

Study	Participants	Country	Purpose	Methodology, study design	Significant results
			and gamification on earth sciences and engineering.	(laptops, smartphones, and tablets)	resulting in an increase in the percentage of passing and average final grades.
Faenza et al. (2021)	392 undergraduate students	Italy	To increase female participations' in STEM and ICT in a summer camp.	Quantitative, survey	Online activities had a positive impact on increasing girls' interest in ICT and STEM fields.
Kadıoğlu-Akbulut et al. (2023)	326 preservice science teachers	Turkey	To examine to what extent ICT usage categories predict preservice science teachers' TPACK.	Quantitative, survey	Approximately a third of the variability in total-TPACK scores can be accounted for by three ICT measures.
Makori et al. (2013)	Library and information science students	Kenya	To examine the use of ICTs in instruction of undergraduate students in universities.	Qualitative, interviews.	Participants lack preferred ICTs knowledge, competencies and skills important in the modern information environment such as web technologies, information programming skills, software development, distributed systems, virtual libraries and digital information systems.
Martínez-Cerdá et al. (2018a)	930 undergraduate students	Spain	To examine the development of collaborative skills through nine tools for ICT-supported pedagogical practices in universities.	Quantitative, survey	E-learning helps develop students' collaborative skills through advanced tools for ICT-supported pedagogical practices.
Martínez-Cerdá et al. (2018b)	550 undergraduate students	Spain	To examine various socio-technical and innovation learning factors that influence the development of skills related to employability.	Quantitative, survey	The ICT-space-time continuum related to the learners' ways of studying has significant positive effects on employability.
Schettini et al. (2020)	526 undergraduate students	Italy	To improve student performance in terms of exam's success through implement an online tutoring course	Quantitative data, Intervention	An increase in students' exam performance and a positive correlation between the time spent on the platform and the mid-term scores achieved.
Sobowale et al. (2024)	50 pre-service teachers	Nigeria	Developed and tested the effectiveness of mobile learning towards improving college of education pre-service teachers' achievement in practical chemistry.	Quantitative, experimental method	Students' performance improved periodically with each testing period after the treatment.

Emerging Themes on ICT Research in Higher STEM Education

Theme 1. Contributions of ICT to skills

Three studies (Kadıoğlu-Akbulut et al., 2023; Martínez-Cerdá et al., 2018a, 2018b) focused on the role and contributions of ICT in higher STEM education. In general, their findings demonstrated the positive impacts of ICT on STEM education. Specifically, the studies showed ICT's contributions to teacher competencies (Kadıoğlu-Akbulut et al., 2023), employment skills (Martínez-Cerdá et al., 2018b), and the development of collaborative skills (Martínez-Cerdá et al., 2018a). These four studies focused on different uses of ICT in higher STEM education. For example, Martínez-Cerdá et al. (2018b) analyzed the impact of ICT on employability and socio-technical systems. The study focuses on the impact of ICT on time-space continuity and learning styles, while Schettini et al. (2020) focused on assessing the impact of ICT-supported online platforms on student performance and exam success. The study of Kadıoğlu-Akbulut et al. (2023) focused on the impact of ICT on teacher competencies and TPACK scores among preservice science teachers. All four studies revealed that

ICT enhances learning outcomes and improves student performance and skill development. For example, results from Kadıoğlu-Akbulut et al. (2023) and Martínez-Cerdá et al. (2018b) indicate that ICT helps develop students' skills, such as proficiency, designing, and employability. In addition, Martínez-Cerdá et al. (2018a) studied how students develop collaboration skills in online universities through ICT-supported teaching methods and reported that e-learning, including gamification, mixed reality, and social media in a fully online university setting, enhances students' collaborative skills.

Theme 2. Gender and the impact of ICT

Alonso et al. (2021) and Faenza et al. (2021) in this theme aimed to increase gender equality and participation in STEM and ICT fields. Faenza et al. (2021) examined the impact of summer camps, and Alonso et al. (2021) analyzed students' motivations and preferences in choosing computer engineering. The research of Faenza et al. (2021) focused on female students participating in summer camps, while Alonso et al. (2021) compared female and male students at the high school and undergraduate levels. In terms of these studies' results, Faenza et al. (2021) noted that summer camps increased female students' interest in STEM and ICT fields, while Alonso et al. (2021) emphasized that gender-based differences are an important factor in academic preferences.

Specifically, findings of Faenza et al. (2021) revealed that face-to-face and online activities had different effects. Summer camps have a positive impact on increasing girls' interest in ICT and STEM fields. Alonso et al. (2021) found significant differences between gender-specific goals and preferred departments. For instance, female students showed more interest in fields such as psychology, criminology, and medicine, while male students gravitated toward sports science and engineering.

Theme 3. The impact of ICT on student performance and academic achievement

Three studies focused on examining the impact of ICT on students' performance and achievement. Gómez-Espina et al. (2019) examined the impact of active learning and ICT compared to traditional methods, while Schettini et al. (2020) and Sobowale et al. (2024) focused on achievement. The study of Gómez-Espina et al. (2019) focused on earth science and engineering students, while Sobowale et al. (2024) involved teacher candidates. Both studies show that ICT-based methods improve academic performance. Specifically, Gómez-Espina et al. (2019) compared traditional approaches and an instruction based on ICT and gamification and found that there was an improvement in academic performance compared to traditional methodologies. Sobowale et al. (2024) tested the effectiveness of mobile learning on pre-service teachers' achievement in practical chemistry. They found statistically significant differences in students' performance. Additionally, the findings of Schettini et al. (2020) show that ICT-supported platforms increase exam success. As a result, the positive effects of ICT in education and its contributions to student performance and skill development have been emphasized in all studies.

Theme 4. Perception and use of ICT

Two researchers examined the perception and uses of ICT in higher STEM education. Barak (2013) examined STEM teacher candidates' attitudes and perceptions toward ICT, while Arenas (2015) investigated students' ICT media preferences and the impact of this media on learning. Barak (2013) focused on STEM teacher candidates, while Arenas (2015) focused on computer science students. Results from these two studies demonstrated that Barak's (2013) study revealed changes in attitudes and perceptions regarding how ICT is perceived by teacher candidates, while Arenas' (2015) study demonstrated how ICT can be beneficial for students in learning activities and which types are more effective.

Theme 5. ICT resources and infrastructure

Two research studies focused on the ICT resources and infrastructure in higher STEM education. Al-Shwabkah et al. (2016) examined the importance of ICT courses in library and information science programs and students' perceptions of these courses in Jordan, while Makori et al. (2013) investigated the shortcomings of ICT education among library and information science students in Kenya and proposed improvements. Concerning their results, Al-Shwabkah et al. (2016) emphasized the importance of ICT courses and the adequacy of existing resources, while finding that students rated the curriculum and pedagogy as average.

Table 4. Challenges regarding ICT use in reviewed studies

Studies	Challenges
Makori et al. (2013)	• Inadequate computer laboratories • Inadequate computer hardware and equipment • Inadequate software packages
Barak (2013)	• Low confidence in the benefits of ICTs • Low confidence in the idea that ICTs can facilitate better understanding of learning materials
Arenas (2015)	• Difficulties with the particular array of ICT-mediated learning activities that they experienced • ICT-mediated learning environment did not give them the option to choose from learning tasks

Findings by Makori et al. (2013) revealed that students lack ICT skills that are important in the modern information environment and that these deficiencies need to be addressed.

Challenges

We also analyzed challenges and difficulties that researchers in the articles we analyzed reported in their studies. **Table 4** shows a list of challenges researchers faced in ICT. Accordingly, difficulties related to ICT use generally arise from infrastructure deficiencies (Makori et al., 2013) or adaptation problems stemming from students' perceptions of ICT-supported learning environments (Arenas, 2015; Barak, 2013). Many studies we reviewed in this study did not report any difficulties in ICT use. For example, Makori et al. (2013) found some challenges regarding insufficient computer labs, computer hardware and equipment, and insufficient software packages. In their study, these emerged as fundamental issues hindering ICT education and instruction for undergraduate library and information science (LIS) students at universities. In the study of Barak (2013), he found challenges concerning low confidence in the benefits of ICT and the idea that ICT can facilitate a better understanding of learning materials. Arenas (2015) found that some students have experienced difficulties in certain ICT-supported learning activities. In addition, he/she found that students have stated that the ICT-supported learning environment does not give them the opportunity to choose between learning tasks and that these tasks are not compatible with their preferences and needs.

DISCUSSION

This paper aimed to review systematically the findings of studies to assess how ICT is used in higher STEM education contexts. Our findings revealed 5 emerging themes from ICT research in higher STEM education. The first theme revealed from the research we reviewed is about the contributions of ICT to skills. Our findings demonstrate that the integration of ICT in higher STEM education has been found to benefit the development of skills such as teacher competencies, employment skills, and the development of collaborative skills. Among possible reasons, the first reason may stem from the fact that the incorporation of ICT has been shown to catalyze improvements in student self-efficacy (Faenza et al., 2021). Secondly, the integration of ICT into educational contexts contributes significantly to enhancing both teaching and learning experiences. This contribution of ICT to skill development is evidenced by research on TPACK. For example, Tondeur et al. (2019) illustrated how training programs increasingly focus on developing pre-service teachers' skills, expanding their capabilities in using technology innovatively for educational purposes (Tondeur et al., 2019). Similar to this, Kadıoğlu-Akbulut et al. (2023) found that approximately a third of the variability in total-TPACK scores can be accounted for by three ICT measures. In addition, another reason may be that effective ICT integration enables learners to collaborate with peers and instructors, and these interactions help to develop their skills during their learning. Further support for this theme comes from research on e-learning and socio-technical factors. Martínez-Cerdá et al. (2018) found that e-learning helped develop students' collaborative skills through a set of nine tools used for ICT-supported pedagogical practices, while in a related study, Martínez-Cerdá et al. (2018b) reported that the ICT-related space-time continuum in students' ways of studying had significant positive effects on their employability. Taken together with the findings on TPACK and self-efficacy discussed above, these results suggest that ICT contributes to skill development across several distinct dimensions, ranging from collaboration and employability to teaching competence. In summary, our results regarding the contribution of ICT to skills show that the ICT tools can assist higher education students in developing skills in different learning contexts.

The second theme is about gender and the impact of ICT. Our findings demonstrate that research was successful in increasing gender equality and participation in STEM using ICT tools. This finding confirms those of earlier research on ICT and the gender gap. Studies show that ICT is an important tool for breaking down the barriers for women and disadvantaged groups. ICT tools help disadvantaged groups have a chance to take advantage of educational opportunities. Hence, designed implementations including women's digital skills through ICT platforms are very helpful for women to participate in STEM fields. For example, findings of Faenza et al. (2021) revealed that summer camps had a positive impact on increasing girls' interest in ICT and STEM fields. In a related study, Alonso et al. (2021) found significant gender differences concerning goals and degree preferences among undergraduate students, particularly regarding the motivations of girls to choose computer engineering; this finding, alongside the results of Faenza et al. (2021), points to the value of interventions that specifically target girls' motivations and interests rather than treating gender gaps in STEM as a uniform problem. It is important to note, however, that this theme rests on evidence from only two of the twelve reviewed studies (Alonso et al., 2021; Faenza et al., 2021), both conducted in the European context; consequently, the extent to which ICT-based interventions can reliably narrow gender gaps in STEM across other cultural and institutional settings remains an open question that warrants further, more geographically diverse research.

The third theme is about the impact of ICT on student performance and academic achievement in higher STEM education. Our findings demonstrate that the research using ICT tools was successful in increasing student performance and achievement in different fields and topics. Namely, researchers have reported the positive effects of ICT in education and its contributions to student performance (Gómez-Espina et al., 2019; Schettini et al., 2020; Sobowale et al., 2024). One of the most important reasons may stem from the engagement of students via ICT tools in instruction. For example, Gómez-Espina et al. (2019) used interactive tools named Socrative, and they found an increase in students' engagement via ICT tools and also better academic achievement. However, the use of more technology-related knowledge and tools does not necessarily lead to better academic performance and technology integration into instruction (Kadıoğlu-Akbulut et al., 2023). For effective implementation of ICT in higher education, there is a need for teachers' understanding of how content knowledge and technology can combine to support instruction for instructors in higher education institutions.

The fourth theme is about the perception and use of ICT in higher STEM education. Our findings demonstrate that ICT can be beneficial for participants in learning activities in higher STEM education. In earlier studies, it has been found that the use of ICT in education has many advantages for student engagement and captures their interest using technological tools in higher education. In particular, research has revealed that ICT-supported active learning environments result in improved understanding and retention of knowledge. While perceptions were largely positive across the reviewed studies, the strength of this positivity appeared to vary by discipline and technology type: for instance, participants in library and information science contexts emphasized the practical necessity of ICT courses (Al-Shwabkah et al., 2016), whereas participants engaging with simulation-based tools reported more mixed perceptions tied to reduced task choice and autonomy (Arenas, 2015). This contrast suggests that positive perceptions of ICT are not uniform but are shaped by how much control and flexibility a given tool affords learners. This pattern is supported by findings from the reviewed studies themselves. Arenas (2015) found that most undergraduate students perceived the integration of ICT into learning activities as useful, convenient, and flexible, and as encouraging reflection, knowledge sharing, and asynchronous interaction. However, perceptions of ICT were not uniformly positive across all groups; Barak (2013) found a gap between preservice STEM teachers' inclination to align with educational trends and their actual views about ICT use, even though these teachers ultimately perceived ICT as instrumental for advancing progressive education. This suggests that positive perceptions of ICT, while common, may take time to fully form and can initially be shaped by broader expectations about educational trends rather than direct experience with the tools themselves. Hence, it is normal that higher education students have positive views of ICT.

The fifth theme is about ICT resources and infrastructure in education in higher STEM education. Our findings demonstrate that researchers have emphasized the importance of the adequacy of existing resources for using ICT tools effectively in higher STEM education. In particular, in implementing ICT tools effectively in higher education, having enough resources has a positive impact on how ICT courses are taught

(Al-Shwabkah et al., 2016). For this, it is important to have enough ICT resources to enable productive teaching and learning environments. This pattern suggests that resource adequacy functions less as a standalone benefit and more as a precondition for the other four themes identified in this review: without sufficient infrastructure, gains in skill development, performance, and positive perception are unlikely to materialize, which may explain why institutions with limited technological infrastructure (e.g., Makori et al., 2013) reported comparatively more implementation challenges than better-resourced contexts.

Implications for Policy and Practice

Building directly on the five themes identified above, we propose the following priority actions. First, given the centrality of the resource theme, institutions should prioritize investment in reliable ICT infrastructure and technical support, as inadequate resources were repeatedly linked to implementation difficulties (Al-Shwabkah et al., 2016; Makori et al., 2013); as indicated by Korsah (2024), providing such facilitating conditions for both learners and instructors is essential to enhancing the effectiveness of ICT tools in universities. Second, professional development programs should specifically target TPACK development, since ICT-related measures accounted for a substantial share of variance in TPACK scores among preservice teachers (Kadıoğlu-Akbulut et al., 2023). Third, gender-focused interventions such as ICT-based summer camps (Faenza et al., 2021) should be piloted and evaluated across a wider range of STEM disciplines and institutional contexts. Fourth, as new tools such as augmented reality and AI-based applications become more widely available, institutions should provide targeted training that helps instructors integrate these tools without assuming that adoption alone will improve performance (Kadıoğlu-Akbulut et al., 2023).

For researchers and scholars, it is necessary to continue to study the effects of ICT tools in higher STEM education and produce more studies to report the effects of ICT on students' learning outcomes and skill development. Given that no study has reviewed a systematic review of ICT research in higher STEM education, there is a need to conduct more studies to examine the effects of ICT on higher STEM education in the future. Particularly, AI and related technologies that are placed in the digital ICT paradigm will continue to be launched more in the future, and they will be used in learning and teaching. Because of this reason, there is a need for researchers to examine the effects of digital ICT tools, including AI and related technologies, on learning and teaching. Thus, we suggest that scholars examine the effects of digital ICT tools and report their findings for higher STEM education.

Limitations

This systematic review has several limitations that should be considered when interpreting its findings. First, this review relied exclusively on the Scopus database; although Scopus offers broad multidisciplinary coverage, relevant studies indexed only in other databases (e.g., Web of Science, ERIC, or PubMed) may have been omitted, which may limit the comprehensiveness of the identified evidence base. Second, the relatively small number of eligible studies (12 articles) restricts the extent to which findings can be generalized across the wide range of STEM disciplines, institutional contexts, and countries; the thematic patterns identified here should therefore be interpreted as indicative rather than definitive. Third, as with most systematic reviews, this study is subject to potential publication bias, since studies reporting positive or significant findings regarding ICT are more likely to be published than those reporting null or negative results, which may have inflated the apparent consistency of positive findings in favor of ICT integration. Finally, we did not include other types of publication such as book chapters, conference papers, or editorials, and several variables reported inconsistently across the included studies (e.g., research design and data collection tools) may have affected comparability of findings.

CONCLUSION & RECOMMENDATIONS

This systematic review provides the first synthesis of empirical research specifically examining ICT use in higher STEM education, addressing a gap left open by prior reviews that have focused predominantly on secondary or preschool contexts. Beyond confirming that ICT tools are broadly associated with positive outcomes, this synthesis reveals that these benefits are conditional: they depend on adequate resource infrastructure, are unevenly distributed across disciplines and genders, and vary with the degree of learner autonomy a given tool affords. These insights move beyond a simple confirmation that 'ICT helps' toward a more precise account of when and for whom ICT integration is most likely to succeed in higher STEM education.

Future research would benefit from several specific directions. First, longitudinal and experimental designs are needed to establish whether the associations identified here (e.g., between ICT use and academic performance) reflect causal effects rather than correlational patterns. Second, future systematic reviews should broaden database coverage beyond Scopus (e.g., incorporating Web of Science and ERIC) to capture a larger and more diverse evidence base. Third, given the concentration of current evidence in a small number of STEM subfields, future studies should disaggregate findings by discipline (e.g., engineering, life sciences, and mathematics) to determine whether the identified themes generalize across STEM areas. Finally, as AI-based and augmented/virtual reality tools become more prevalent, future research should specifically evaluate their effects on skill development, gender equity, and performance in higher STEM education, building on the resource and perception themes identified in this review.

Author contributions: EMI: conceptualization, formal analysis, investigation, methodology, project administration, writing – original draft; **VGG:** data curation, formal analysis, investigation, writing – review & editing; **LYG:** data curation, investigation, visualization, writing – review & editing; **NAZ:** investigation, methodology, validation, writing – review & editing; **EZ:** investigation, validation, writing – review & editing; **SVK:** resources, supervision, validation, writing – review & editing. All authors approved the final version of the article.

Funding: The authors received no financial support for the research and/or authorship of this article.

Ethics declaration: Since this study is a systematic review and does not involve primary data collection from human or animal subjects, ethical committee approval was not required. The study was conducted in accordance with ethical standards for review research.

AI statement: The authors declare that no artificial intelligence (AI) or AI-assisted technologies were utilized in the preparation, analysis, or writing of this manuscript.

Declaration of interest: The authors declared no competing interest.

Data availability: Data generated or analyzed during this study are available from the authors on request.

REFERENCES

Aboderin, O., & Bamisile, O. (2021). Students' perception on the influence of information and communication technology (ICT) in science teaching and learning on their ICT and teaching skills. *International Journal of Online and Distance Learning, 1*(1), 79-88. https://doi.org/10.47604/ijodl.1319

Alonso, M. T., Barba-Sánchez, V., Bonal, M. T. L., & Macià, H. (2021). Two perspectives on the gender gap in computer engineering: From secondary school to higher education. *Sustainability, 13*(18), Article 10445. https://doi.org/10.3390/su131810445

Al-Shwabkah, Y., Hamad, F., Taha, N., & Al-Fadel, M. (2016). The integration of ICT in library and information science curriculum analytical study of students' perception in Jordanian universities. *Library Review, 65*(6/7), 461-478. https://doi.org/10.1108/lr-12-2015-0115

Alzahrani, A. (2025). A systematic review of the use of information communication technology, including augmented reality, in the teaching of science to preschool children. *International Journal of Educational Research Open, 9*, Article 100453. https://doi.org/10.1016/j.ijedro.2025.100453

Anastasopoulou, E., Tsagri, A., Avramidis, E., Lourida, K., Mitroyannis, E., Tsogka, D., & Katsikis, I. (2024). The impact of ICT on education. *Technium Social Sciences Journal, 58*, 48-55. https://doi.org/10.47577/tssj.v58i1.11144

Arenas, E. (2015). Affordances of educational learning technologies in higher education multicultural environments multicultural learning environments. *Electronic Journal of E-Learning, 13*(4), 217-227.

Bandoh, S. O., Akweittey, E., Lotey, E. K., Gordon, J. F., & Appiagyei, E. (2024). Using UTAUT model to assess the factors influencing the use of ICT in Ghanaian pre-tertiary mathematics education. *Journal of Digital Educational Technology, 4*(1), Article ep2407. https://doi.org/10.30935/jdet/14297

Barak, M. (2013). Closing the gap between attitudes and perceptions about ICT-enhanced learning among pre-service STEM teachers. *Journal of Science Education and Technology, 23*, 1-14. https://doi.org/10.1007/s10956-013-9446-8

Basargekar, P., & Singhavi, C. (2017). Factors affecting teachers' perceived proficiency in using ICT in the classroom. *IAFOR Journal of Education, 5*(2), 67-84. https://doi.org/10.22492/ije.5.2.03

Beichumila, F., Bahati, B., & Kafanabo, E. (2022). Computer simulations and animations in the teaching and learning of chemical kinetics, equilibrium, and energetics: Assessing teachers' pedagogical skills in Tanzania secondary schools. *Eurasia Journal of Mathematics Science and Technology Education, 18*(11), Article em2174. https://doi.org/10.29333/ejmste/12498

Bellou, I., Papachristos, N. M., Mikropoulos, T. A. (2018). Digital learning technologies in chemistry education: A review. In D. Sampson, D. Ifenthaler, J. Spector, & P. Isaías, P. (Eds.), *Digital technologies: Sustainable innovations for improving teaching and learning* (pp. 57-80). Springer. https://doi.org/10.1007/978-3-319-73417-0_4

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(1), 77-101. https://doi.org/10.1191/1478088706qp063oa

Faenza, F., Canali, C., Colajanni, M., & Carbonaro, A. (2021). The digital girls response to pandemic: Impacts of in presence and online extracurricular activities on girls future academic choices. *Education Sciences, 11*(11), Article 715. https://doi.org/10.3390/educsci11110715

Gómez-Espina, R., Rodríguez-Oroz, D., Chávez, M., Saavedra, C., & Bravo, M. J. (2019). Assessment of the Socrative platform as an interactive and didactic tool in the performance improvement of STEM university students. *Higher Learning Research Communications, 9*(2). https://doi.org/10.18870/hlrc.v9i2.438

Kadıoğlu-Akbulut, C., Cetin-Dindar, A., Acar-Şeşen, B., & Küçük, S. (2023). Predicting preservice science teachers' TPACK through ICT usage. *Education and Information Technologies, 28*(9), 11269-11289. https://doi.org/10.1007/s10639-023-11657-0

Kewalramani, S., & Havu-Nuutinen, S. (2019). Preschool teachers' beliefs and pedagogical practices in the integration of technology: A case for engaging young children in scientific inquiry. *Eurasia Journal of Mathematics, Science and Technology Education, 15*(12), Article em1784. https://doi.org/10.29333/ejmste/109949

Khan, K. S., Kunz, R., Kleijnen, J., & Antes, G. (2003). Five steps to conducting a systematic review. *Journal of the Royal Society of Medicine, 96*(3), 118-121. https://doi.org/10.1177/014107680309600304

Korsah, D. P. (2024). Adoption and utilization of Moodle learning management system for emergency remote teaching: A UTAUT perspective. *Educational Point, 1*(2), Article e111. https://doi.org/10.71176/edup/15730

Liang, M., Lim, C. P., Park, J., & Mendoza, N. B. (2022). A review of ICT-enabled learning for schoolgirls in Asia and its impacts on education equity. *Educational Technology Research and Development, 71*(2), 267-293. https://doi.org/10.1007/s11423-022-10178-w

Makori, E. O., Odini, C., & Ojiambo, J. B. (2013). Use of information communication technologies in education and training of undergraduate library and information science students in two selected Kenyan universities. *Library Review, 62*(8/9), 585-601. https://doi.org/10.1108/lr-08-2012-0083

Martínez-Cerdá, J., Torrent-Sellens, J., & González-González, I. (2018a). Promoting collaborative skills in online university: Comparing effects of games, mixed reality, social media, and other tools for ICT-supported pedagogical practices. *Behaviour and Information Technology, 37*(10-11), 1055-1071. https://doi.org/10.1080/0144929x.2018.1476919

Martínez-Cerdá, J., Torrent-Sellens, J., & González-González, I. (2018b). Socio-technical e-learning innovation and ways of learning in the ICT-space-time continuum to improve the employability skills of adults. *Computers in Human Behavior, 107*, Article 105753. https://doi.org/10.1016/j.chb.2018.10.019

Msafiri, M. M., Kangwa, D., & Cai, L. (2023). A systematic literature review of ICT integration in secondary education: What works, what does not, and what next? *Discover Education, 2*, Article 44. https://doi.org/10.1007/s44217-023-00070-x

Msambwa, M. M., & Daniel, K. (2024). A systematic literature review on the ICT integration in teaching and learning: Lessons for an effective integration in Tanzania. *European Journal of Education, 59*(4), Article e12696. https://doi.org/10.1111/ejed.12696

Msambwa, M. M., Daniel, K., & Lianyu, C. (2024). Integration of information and communication technology in secondary education for better learning: A systematic literature review. *Social Sciences & Humanities Open, 10*, Article 101203. https://doi.org/10.1016/j.ssaho.2024.101203

Navarro-Ibarra, L., Cuevas-Salazar, O., & Robles-Aguilar, A. (2023). Knowledge gaps in education and ICT: A literature review in open access publications. *Contemporary Educational Technology, 15*(4), Article ep480. https://doi.org/10.30935/cedtech/13770

Page, M. J., Moher, D., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., . . . McKenzie, J. E. (2021). PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. *BMJ, 372*, Article n160. https://doi.org/10.1136/bmj.n160

Pham, Q., Ngoc, T. N., Thi, H. D., & Thi, H. D. (2025). Factors influencing high school teachers' use of ICT in teaching mathematics: Insights from Northern Vietnam. *Contemporary Mathematics and Science Education, 6*(2), Article ep25010. https://doi.org/10.30935/conmaths/16437

Rutten, N., van Joolingen, W. R., & van der Veen, J. T. (2012). The learning effects of computer simulations in science education. *Computers & Education, 58*(1), 136-153. https://doi.org/10.1016/j.compedu.2011.07.017

Saltan, F., Türkyılmaz, T., Karaçaltı, C., & Bilir, K. (2018). Use of current educational technology in science education: A scoping review. *Cukurova University Faculty of Education Journal, 47*(1), 308-336. https://doi.org/10.14812/cuefd.304015

Sasota, R. S., Cristobal, R. R., Sario, I. S., Biyo, J. T., & Magadia, J. C. (2021). Will-skill-tool (WST) model of technology integration in teaching science and mathematics in the Philippines. *Journal of Computers in Education, 8*(3), 443-464. https://doi.org/10.1007/s40692-021-00185-w

Schettini, C., Amendola, D., Borsini, I., & Galassi, R. (2020). A blended learning approach for general chemistry modules using a Moodle platform for first year academic students. *Journal of E-Learning and Knowledge Society, 16*(2), 61-72. https://doi.org/10.20368/1971-8829/1135197

Sobowale, F. M., Mohammed, I. A., Ali, F., Samson, B. M., & Sadiku, A. (2024). Development and evaluation of mobile learning application for practical chemistry among pre-service teachers. *Discover Education, 3*, Article 252. https://doi.org/10.1007/s44217-024-00352-y

Tondeur, J., Scherer, R., Siddiq, F., & Baran, E. (2019). Enhancing pre-service teachers' technological pedagogical content knowledge (TPACK): A mixed-method study. *Educational Technology Research and Development, 68*(1), 319-343. https://doi.org/10.1007/s11423-019-09692-1

Zakaria, N. A., & Khalid, F. (2016). The benefits and constraints of the use of information and communication technology (ICT) in teaching mathematics. *Creative Education, 7*(11), 1537-1544. https://doi.org/10.4236/ce.2016.711158