RECENT TRENDS IN APPLYING INTELLIGENT EDUCATIONAL TECHNOLOGIES IN STEM EDUCATION

Valentina Terzieva
Institute of Information and Communication Technologies, Bulgarian Academy of Sciences, Bulgaria
valentina.terzieva@iict.bas.bg

Edita Djambazova
Institute of Information and Communication Technologies, Bulgarian Academy of Sciences, Bulgaria
edita.djambazova@iict.bas.bg

СЪВРЕМЕННИ ТЕНДЕНЦИИ В ПРИЛАГАНЕТО НА ИНТЕЛИГЕНТНИ ОБРАЗОВАТЕЛНИ ТЕХНОЛОГИИ В STEM ОБУЧЕНИЕТО

Abstract

Contemporary education is being reshaped thanks to the transformative impact of various emerging intelligent educational technologies (IETs). This paper presents a bibliometric analysis of trends in the last five years in the application of IETs in science, technology, engineering, and mathematics (STEM) education. The review highlights the intelligent technologies used to enhance the teaching process and foster skill development and learner engagement. According to the bibliometric analysis, the IETs most applied in the STEM context are virtual and augmented reality, with more than 30% of publications, followed by artificial intelligence and machine learning. Additionally, the study makes a comprehensive overview of both the opportunities and challenges associated with the integration of IETs in STEM education. It provides a complete view of diverse intelligent technologies, and its findings suggest that applying IETs in STEM education offers opportunities for personalized teaching and learning. Combining various smart technologies can lead to more individualized task assignments, personal assessment, and individual learning paths. IETs introduce possibilities for collaboration, thus making the learning experience more engaging and efficient. They can be very beneficial in assisting the multidisciplinary STEM education by providing different and comprehensive viewpoints on a problem. Applying several IETs together can leverage the successful comprehension of complex STEM concepts.

Keywords: *STEM Education; Intelligent Educational Technologies; Trends; Bibliometric Analysis.*

1. INTRODUCTION

Intelligent technologies can be considered an umbrella term embracing different devices and systems that can perform activities like humans, e.g., learning, answering questions, and making decisions. They usually leverage artificial intelligence, machine learning, neural networks, large language models, or specific software solutions. In education, they help automate routine tasks and create learning resources, facilitate teaching and learning, assist personalization, and enhance the assessment process [1]. Therefore, when applied in an educational context, these technologies are considered Intelligent Educational Technologies (IETs). They are innovative tools that change the educational process entirely, making it more adaptable to students' needs and abilities, offering an enhanced learning experience, and providing multiple learning paths. These technologies can completely raise the educational process to a new level, making it student-centered, flexible, personalized, and efficient [2].

STEM (Science, Technology, Engineering, Mathematics) education focuses on preparing students from an early age to pursue careers that match the necessities of contemporary economic [3]. It is usually interdisciplinary, project-oriented, and combines theory and practice. STEM education develops critical thinking, teamwork, co-operation, analytical thinking, technical skills, and other abilities needed for the 21st-century professions [4]. The STEM-related disciplines need an innovative form of teaching and learning that applies IETs to carry out problem-based, project-oriented, and other activity-based student-centered pedagogical approaches. IETs introduce innovative tools into the educational process, preparing students for the professions of the future [5].

Many scientific literature reviews examine the application of IETs in education in general [6], [7], [8]. There are studies on their use in STEM education as well [9]. As the application of various IETs has intensified in recent years, their role in STEM education needs to be more thoroughly explored. The goal of this paper is to outline research trends in applying IETs in STEM education and seek opportunities and new scientific directions and practical implications for STEM teaching and learning. It provides a bibliometric research on IET-related terms in the context of STEM education to answer the following research questions:

RQ1: What is the role of each of the searched IETs in STEM education?

RQ2: What practical implications can be derived from the application of IETs in STEM education?

To answer these research questions, the authors performed a bibliometric study of the application of intelligent educational technologies in STEM education for the last five years (2020-2025). Thus, publications considering the eight most commonly utilized technologies, including artificial intelligence, big data, data mining, virtual or augmented reality, learning analytics, large language models, machine learning, and neural networks, are identified and analyzed. A strong tendency in the annual growth rate of scientific studies, at nearly 17%, is revealed, which indicates the extensive application of these technologies in STEM teaching. The analysis of bibliometric findings outlines the top three IETs reflected in research publications: virtual or augmented reality, artificial intelligence, and machine learning. They represent above three-fourths of the returned results in the search query. According to the author's keywords, the application context of intelligent educational technologies is usually related to engineering education. The analyzed publications imply that these technologies enable adaptive and personalized STEM education. The overview of IETs and methodology of the survey, along with detailed analysis and discussion of all research findings, is provided in the following sections of the paper.

2. Intelligent Educational Technologies

Intelligent educational technologies are systems and devices that perform human-like, automated, and autonomous functions and assist in decision-making, task-solving, and other analytical activities. They play a transformative role in contemporary education, completely changing how it is delivered and performed, enabling the creation of personalized, adaptive learning environments. Much scientific research explores the application of these technologies in different educational frameworks. Key technologies that have significantly influenced teaching practice include, but are not limited to Machine Learning (ML), Data Mining (DM), Big Data, Neural Networks (NNs), Learning Analytics (LA), Virtual and Augmented Reality (VR/AR), Intelligent Tutoring Systems (ITS), Artificial Intelligence (AI), Natural Language Processing (NLP), and most recently Large Language Models (LLMs) [10], [11], [12], [13], [14]. Some of these technologies have been applied in the educational context for decades;

however, their integration has expanded over the last five years. They are used to support the teaching-learning process in various ways. They can relieve teachers of time-consuming and distracting administrative tasks, help them prepare more individualized assignments, or even assist in assessment. From the students' perspective, IETs can help extract information from a vast amount of sources while preparing their lessons/projects, check their homework, give advice, and be part of their self-learning process. Intelligent technologies offer opportunities to make the educational process student-centered, adaptive to learners' individual needs, and thus more effective [15], [16].

A comprehensive literature review reveals that the application of AI in education has evolved significantly in recent years and now it comprises the adaptation and personalization of the teaching-learning process, intelligent assessment, student profiling, and the management of the education process, among others [17]. AI in education covers applications for adaptive and personalized learning, intelligent assessment and management, and predicting performance and drop-outs [18]. According to numerous scientific surveys, artificial intelligence in education is one of the emerging fields in educational technology, despite being researched for several decades. The integration of artificial intelligence is changing the way teaching and learning occur; however, it arouses both furor and worry about its potential to transform education [18], [19]. A taxonomy identifies ten distinct domains and provides a framework for ongoing investigations, understanding of AI's role in education, and ensuring its effective implementation. It outlines a clear structure to consider the multifaceted impacts of AI on educational leadership, including administrative efficiency, personalized learning, enhanced student engagement, and others in higher education leadership [20].

In the comprehensive review of intelligent technologies in smart education [21], the authors outline the following technologies that are most frequently mentioned in the studied literature: AI, big data, cloud computing, virtual/augmented reality, Internet of Things (IoT), mobile communication devices, and 5G. The focus of the review is on smart education and its impact on teaching and learning practices. The transformative role of IETs is regarded in this context.

The application of AI technologies in education is studied in [22]. The AI-related technologies that stand out in the literature review include Chatbot, expert systems, intelligent tutors or agents, machine learning, personalized learning systems or environments, and visualizations.

In [7], the promising technologies for teaching and learning are identified as follows: virtual reality, augmented reality, artificial intelligence, the Internet of Things, and cloud computing. Virtual and augmented reality, as well as simulations, support the creation of immersive, interactive learning experiences for exploring STEM concepts or phenomena and events that would otherwise be inaccessible or unobservable. VR field trips to natural or historical sites; AR apps to hold and examine 3D models related to different STEM subjects, e.g., atoms, human body anatomy, 3D shapes in mathematics and engineering, and process simulations [23], [24], [25].

Considering the variety of intelligent technologies utilized in smart education, the authors applied a heuristic approach based on both screening literature reviews and using their experience and expertise. The IETs selected for investigation are AI, ML, LLMs, NNs, data mining, big data, VR/AR, and learning analytics.

3. METHODOLOGY

The paper presents a bibliometric study of intelligent educational technologies to answer the research questions regarding their role and gain practical implications for their

application in STEM education. A search query was submitted to the scientific databases Scopus and Web of Science on September 5, 2025. The bibliometric study was conducted in two phases. At first, an individual dataset for each studied IET was obtained. The identified inclusion and exclusion criteria were applied to the datasets, and the bibliographic information was then analyzed to outline the specific role of each IET in STEM education. In the second phase, the individual datasets were merged to eliminate duplicates. The complete dataset for all studied IETs was quantitatively and qualitatively explored. The results were discussed and analyzed to outline the opportunities for IETs' application to STEM education and suggest future research directions.

The applied inclusion and exclusion criteria were as follows:

Inclusion criteria:

- publications relevant to the search topic;
- only referred publications, i.e., indexed in WoS and Scopus databases;
- publications that include the terms of the search query in their titles, abstracts, or authors' keywords;
- only documents in English.

Exclusion criteria:

- publications irrelevant to the search topic;
- non-scientific publications – editorials, conference reviews, retracted papers, etc.;
- non-English publications.

The bibliometric study spans 2020-2025. It is limited to the two scientific databases Scopus and WoS, two of the richest sources of bibliographic data about referred publications in the field of information and communication technologies and smart education. The search was focused on titles, abstracts, and authors' keywords. The obtained datasets were statistically analyzed using RStudio and the application bibliometrix:biblioshiny [26]. Some of the publications were selected for qualitative analysis based on their citation index, which reflects their popularity and scientific value.

4. RESULTS

The search query submitted to Scopus and Web of Science for 2020-2025 was as follows:

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("artificial intelligence" OR "big data" OR "data mining" OR "virtual reality" OR "augmented reality" OR "learning analytics" OR "large language models" OR "machine learning" OR "neural networks") AND "STEM education"
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It includes the IETs selected for bibliometric study. The initial set of bibliographic information for all technologies contained 1610 documents. After excluding the duplicates, the complete dataset comprised 1313 publications. The main statistical data for the explored intelligent educational technologies applied in STEM education are summarized in Table 1. The intelligent technologies are ordered by the number of documents they are discussed in (the second row of Table 1), starting from the highest number. The data for all topics is listed in the rightmost column of the table.

4.1 Presence of the individual IETs

The most discussed topics in the research literature are virtual or augmented reality, artificial intelligence, and machine learning. They appear in more than 300 publications each. Large language models demonstrate an impressive indicator of rapid popularity – an annual growth rate of 74.11%. The increasing implementation of chatbots in education can explain this. Publications considering AI, NNs, and ML are also among the intensively studied topics, with an annual growth rate above 25%. Learning analytics seems to lag (negative annual growth rate).

The average number of citations per document reflects a publication's scientific value and research interest in the respective topic. According to this indicator, the most popular topic is big data (17.38 citations per document). VR/AR, learning analytics, and data mining are well represented in this indicator, with citations per document above 10.

Table 1. Statistical data for the studied IETs in STEM education for 2020-2025

Description	VR/AR	AI	ML	Learning analytics	Data mining	LLMs	Big data	NNs	All topics
Sources	220	183	179	138	97	79	54	40	598
Documents	382	366	320	209	119	101	71	47	1313
Annual growth rate, %	6.65	40.22	27.89	-0.6	10.49	74.11	0	28.47	16.96
Document Average Age	2.21	1.45	1.77	2.46	2.14	1.14	2.44	1.85	1.94
Average citations per document	10.77	7.32	5.953	11.18	10.55	4.97	17.38	7.085	8.442
Authors' keywords	939	1820	1742	932	508	422	405	255	4524
Single-authored documents	14	16	12	14	14	6	10	2	72
Co-authors per document	5.56	7.17	7.04	5.76	5.41	5.47	5.31	4.94	6.13
International co-authorships, %	15.71	9.29	13.12	13.88	21.01	10.89	23.94	21.28	14.01

Most publications report a collaborative effort involving more than five authors per document. Single-authored papers are instead an exception rather than a regular case (between 3.5 and 11.8% of the publications in each IET). STEM teaching usually requires interdisciplinary approaches, often combining several disciplines in a project and bringing together professionals with diverse backgrounds and expertise. Intelligent technologies require specific knowledge that must be appropriately introduced to achieve the educational goals. This interdisciplinary collaboration must align with the curricula and be efficient in teaching settings.

International research collaboration ranges from 9% to 24% of the papers. Considering the specific educational systems, this is a good amount of joint work among researchers from different countries.

Publications on IETs in STEM education are mostly journal articles and conference papers (Table 2). Reviews, book chapters, and books are still a relatively small number. The short time span of the study can explain this observation. The intensive research in intelligent educational technologies over the last five years is directed toward forums with rapid feedback, where scientists can discuss their new ideas and findings. It can be expected that the

acquired knowledge and practical experience will be further summarized in more thorough manuscripts.

Table 2. Types of publications

Description	VR/AR	AI	ML	Learning analytics	Data mining	LLMs	Big data	NNs	All topics
Article	168	139	128	108	76	54	37	29	623
Conference paper	170	158	159	70	27	39	22	16	529
Review	28	25	15	21	16	5	6	1	90
Book chapter	15	39	15	9	-	2	1	-	63
Book	1	5	3	1	-	1	1	1	8

4.2 Intelligent educational technologies in STEM education

The complete dataset of 1313 publications was analyzed, and the results are summarized below. There is a clear increasing trend in the number of publications over the last five years. Fig. 1 shows the total number of publications by year for the period. The research papers for 2024 are twice those of the previous year. Publications for 2025 are already exceeding those for 2023 and could reach the level of 2024. The growing trend is also evident in the production of the five leading countries over the period, as depicted in Fig. 2. The USA and China, the two most productive countries, significantly increase their annual number of publications. Spain, Germany, and India also register a growing number of documents, although the total amount is considerably smaller.

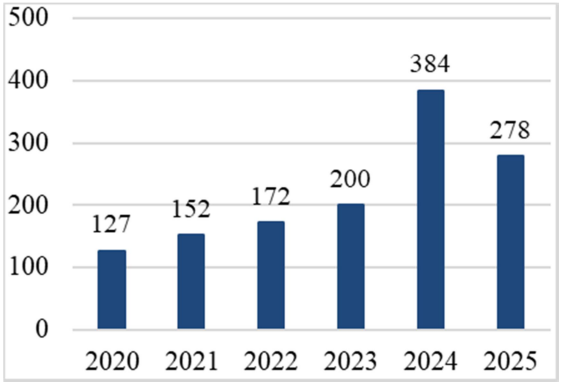

Fig. 1. Number of publications for 2020-2025

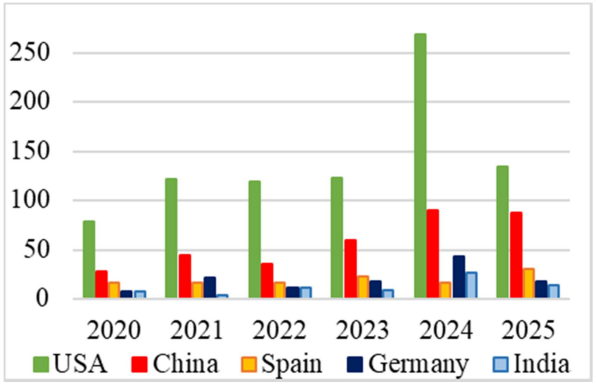

Fig. 2. Countries' production for 2020-2025 by year

The average number of total citations (TCs) per document is decreasing (Fig. 3), as it is logical that more recent publications have fewer citations. The average number of citations per year, however, remains stable – around 3.

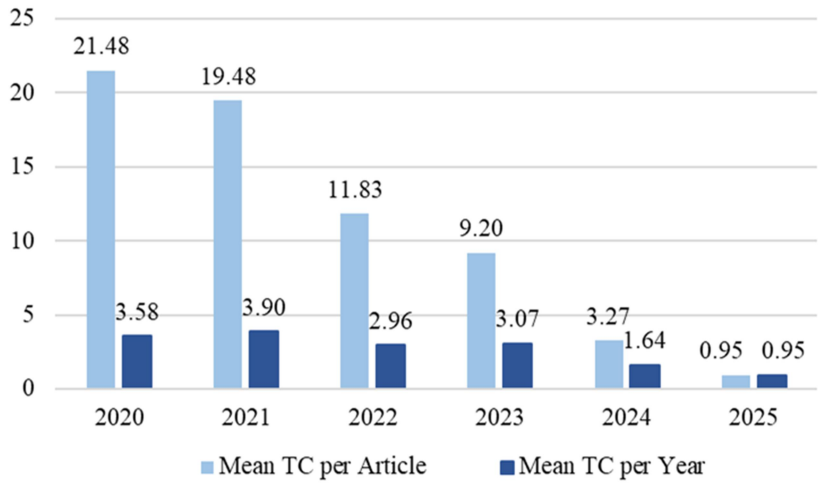

Fig. 3. Average number of citations per year and per article for 2020-2025

The five countries with the highest total number of citations for the period are the USA, China, Spain, Canada, and Australia (Fig. 4), each with more than 300 TCs. There are other countries with a reasonable citation rate (more than 200 TCs) – Greece, Austria, the UK, Turkey, and Malaysia (which has almost 200 TCs).

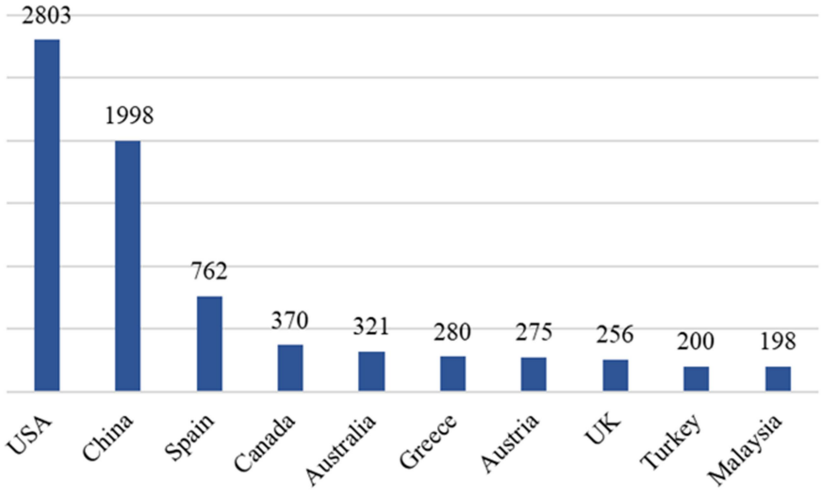

Fig. 4. Total citations for 2020-2025 by country

Results for the relatively small percentage of international co-operation among the researchers (Table 1) are supported by the data for the leading countries (Fig. 5). The countries with the largest number of publications, the USA and China, have a comparatively small percentage of international co-authorships (11.5% and 13.7%, respectively). In countries such as Australia and the United Kingdom, however, this percentage reaches 40%, showing that international partnerships produce substantial research outcomes, given the strong TCs of these countries (Fig. 4).

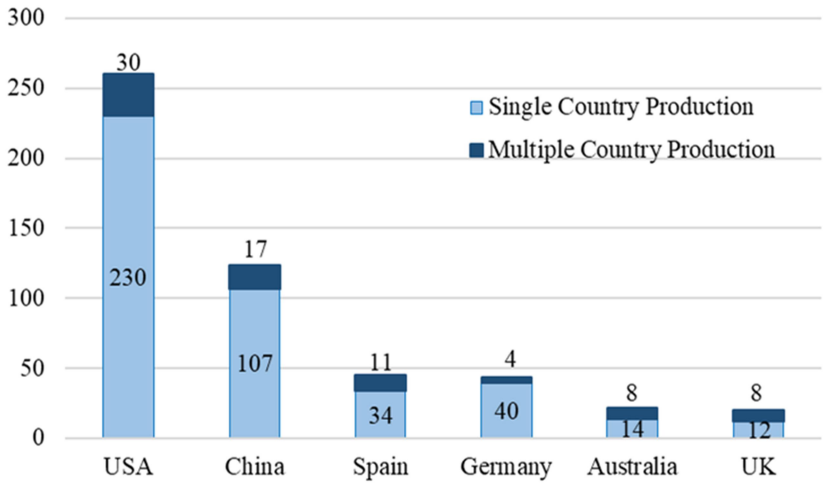

Fig. 5. International cooperation for 2020-2025 by country

The focus of this study was the role of IETs in STEM education. The terms obtained from publication titles, abstracts, and authors' keywords are indicators of the research directions pursued by the scientific community. The most frequently used terms in the publications are summarized in Table 3. Terms that directly repeated the search query were excluded to avoid distorting the picture. The topics discussed most in the scientific literature are "students," "engineering education," and "education," with more than 100 occurrences. Along with "teaching," they represent the instructional process, which is the obvious research context. The presence of "engineering education" in the top-ranked terms suggests that STEM subjects are mainly considered in universities, as sustained by the presence of the term "higher education" in the second most populated group of terms. Another possible explanation is that STEM education prepares students to pursue careers in engineering by continuing their education.

Table 3. Most frequent terms/topics in authors' keywords

Words	Occurrences
students	131
engineering education	127
education	106
teaching	95
adversarial machine learning	69
higher education	65
educational technology	63
contrastive learning	61
ChatGPT	55
federated learning, science education, curricula, science technologies, e-learning, active learning, education computing, mathematics education, engineering and mathematics, learning systems, educational data mining, technology, collaborative learning, learning	30-50
systematic review, computer-aided instruction, generative AI, technology education, immersive learning, computational thinking, deep learning, gamification	20-30

The group of terms with 50-100 occurrences covers three specific topics: adversarial machine learning, contrastive learning, and ChatGPT. Adversarial machine learning is a term that appears relatively often in the publications searched and concerns the security of machine learning algorithms. Its connection to STEM education can be traced after a deeper analysis of the publications. Contrastive learning is an approach to extracting meaningful representations

from unlabeled data. It can be successfully applied in computer vision, natural language processing, and reinforcement learning. ChatGPT [27] is an AI chatbot that uses a large language model to generate human-like text in response to a user's prompts. In education, it can be used to answer questions, write content, and provide summaries.

The co-occurrence network of terms in authors' keywords (Fig. 6) shows relationships among the most frequently used terms. There are three big clusters in the figure and a smaller one without a dominating topic. The STEM-centered cluster (in red in Fig. 6) embraces terms related to STEM education, such as "active learning," "augmented reality," "virtual reality," "immersive learning," "gamification," and "learning analytics." They represent IETs and approaches applicable to STEM teaching.

The blue cluster (Fig. 6) centers on artificial intelligence, with related terms such as "generative artificial intelligence/AI," "large language model(s)," "ChatGPT," "deep learning," and "machine learning." They represent one of the most rapidly developing smart technologies, finding its place in education. The green cluster is associated with the teaching-learning process. The most outstanding terms here are "students," "teaching," "engineering education," and "STEM." Also, it is worth noting the presence of terms related to the applied approaches to "computer-aided instruction," "e-learning," "data mining," and "machine learning."

The small purple cluster in Fig. 6 encompasses terms related to STEM disciplines, such as "science, technology, engineering," "engineering and mathematics," "science education," "mathematics education," and "technology education." They are equally represented within the purple cluster and have relations to the student-centered cluster (the green one).

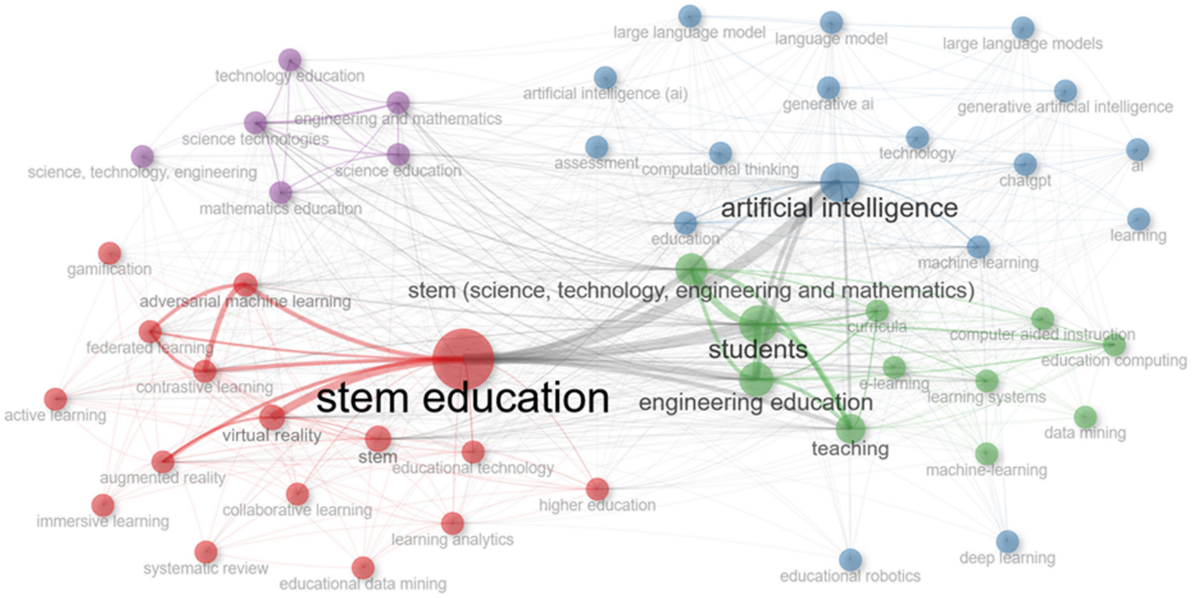

Fig. 6. Co-occurrence network of terms in authors' keywords for 2020-2025

The trend topics outlined according to their occurrences during the period are "education computing" and "generative AI" (Fig. 7). "STEM education" and "artificial intelligence" in general are among the most studied topics. Intelligent technologies such as virtual and augmented reality and learning analytics are closely related to STEM education and are often present in research publications.

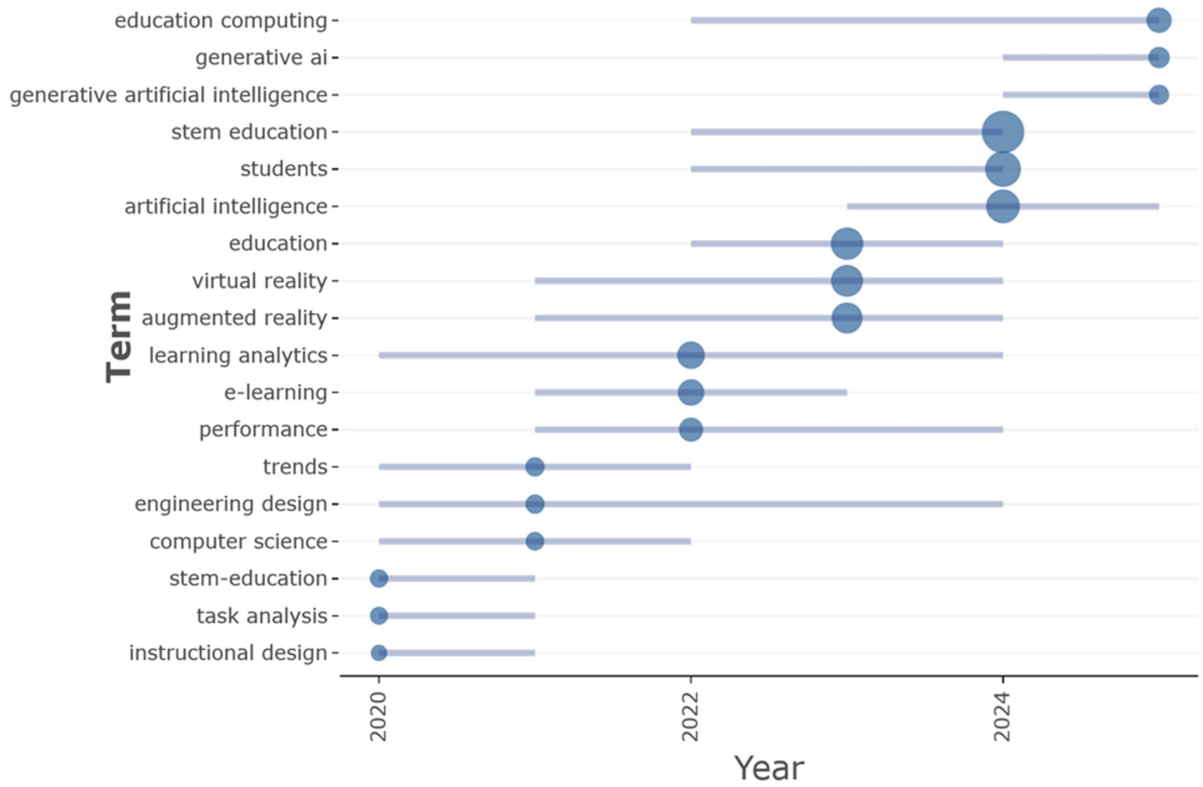

Fig. 7. Trend topics in authors' keywords for 2020-2025

The studied period of five years is relatively short, but some of the terms appear in publications only during this time span, as these IETs are intensively studied and applied in STEM education. STEM teaching itself is a rather new approach that is gaining popularity because of its effectiveness. Some implications about terms development since 2020 can be derived from Fig. 8.

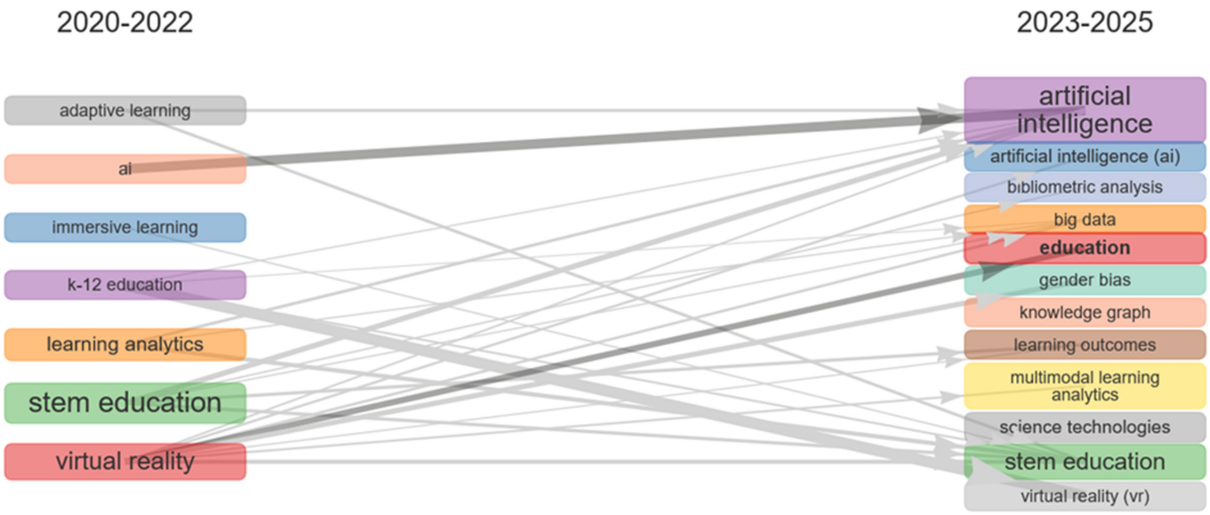

Fig. 8. Thematic evolution in authors' keywords for 2020-2025

Adaptive learning, a personalization approach, is applied in STEM education, as evidenced by the publications after 2023. Immersive learning, aided by VR/AR, is also related to STEM education. The latter develops to the use of artificial intelligence. K-12 education strongly involves STEM teaching.

5. DISCUSSION

The results reported in the previous section shape the role of the searched IETs in STEM education (RQ1). The findings underline the growing research on intelligent educational technologies applied in STEM education. The number of publications discussing most of the eight studied IETs increases. Only learning analytics and big data seem to lack research attention recently, as the number of publications decreases or does not grow. The most cited publications, however, are related to big data (citation index per article over 17), while documents discussing learning analytics have more than ten citations per document on average. It can be expected that these two topics will be studied more intensively to analyze accumulated data.

Almost one-third of the publications concern VR/AR in STEM education. Research community explores the ability of these technologies to provide immersive and attractive lesson presentations, where students can be part of the process, thus perceiving knowledge from a first-hand experience.

The research interest in AI is growing. AI applications in education are rapidly increasing. STEM education, with its focus on student-centered instructional process and development of 21st-century skills, is a favorable environment for this smart technology. Machine learning is another area of extensive research. It can be applied to predict students' performance, classify students in groups for project work, and support learning analytics.

Smart technologies are developing fast, and we had to constrain the focus of our study to derive meaningful results. Other IETs worth exploring remained out of the scope of our bibliometric analysis, such as the Internet of Things and cloud computing. Their application in STEM education deserves deeper investigation.

Bibliometric analysis of the complete dataset of 1313 publications led to practical implications about the application of IETs in STEM education (RQ2). Applying IETs in STEM education offers opportunities for personalized teaching and learning, and combining various smart technologies can lead to more individualized task assignments, personal assessment, and individual learning paths. The nature of STEM teaching to blend theoretical and practical knowledge and skills supports the usage of pedagogical approaches, such as project-based and problem-solving learning. IETs introduce additional possibilities for collaboration, thus making the learning experience more engaging and efficient. IETs can effectively assist the multidisciplinarity of STEM education by providing different and comprehensive viewpoints on a problem. Combined application of several IETs can leverage the successful comprehension of complex STEM concepts.

6. CONCLUSION

The paper presented a bibliometric study of the application of intelligent educational technologies in STEM education for 2020-2025. Publications related to eight IETs were analyzed. The goal was to identify scientific trends and derive practical implications from the utilization of IETs in STEM teaching.

Intelligent educational technologies are extensively applied in STEM education. There are over 1300 publications dedicated to this topic in the last five years, representing an annual growth rate of 16.96%. The two areas seem to find a common playground where their characteristics support the flexible and effective educational process.

According to our bibliometric study, the most commonly used technologies are virtual and augmented reality, with 29% of publications. Artificial intelligence and machine learning also have more than 300 publications during the period 2020-2025. Other popular IETs

include learning analytics, data mining, and LLMs, each with over 100 publications. Generative AI is a trending topic.

IETs make the STEM learning process more adaptive and personalized, and teaching STEM disciplines more effective. The opportunities for personalizing STEM education by applying IETs will be explored in our future work. The role of other IETs in STEM education, such as robotics, game-based learning, and the IoT, will be other research directions worth pursuing. The application of IETs in higher education and their suitability for K-12 have to be further studied as well.

ACKNOWWEDGMENT

This research is supported by the Bulgarian National Science Fund through the project "ReSearcH on formAl models for the oPtimization and pErsonalization of modern technological methods of STEM education (SHAPES)", contract КП-06- H75/11 /08.12.2023.

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Received: 20-10-2025 Accepted: 19-12-2025 Published: 29-12-2025

Cite as:
Terzieva, V., Djambazova, E. (2025). "Recent Trends in Applying Intelligent Educational Technologies in STEM Education", Science Series "Innovative STEM Education", volume 07, ISSN: 2683-1333, pp. 291-303, 2025.
DOI: https://doi.org/10.55630/STEM.2025.0726