applied sciences

Review

# Augmented Reality, Virtual Reality, and Intelligent Tutoring Systems in Education and Training: A Systematic Literature Review

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**Abstract:** Given the advancements in artificial intelligence and extended reality technologies, this study aims to examine the integration of intelligent tutoring systems into augmented reality and virtual reality environments through a systematic literature review. Following the PRISMA framework, 32 related theoretical, showcase, and case studies published during the period of 2015–2024 are examined. Based on the results, this combination of technologies emerged as an effective educational means that can support both students and teachers, promote lifelong learning, and support face-to-face, blended, and online learning across educational levels and in the workplace. These systems offered immersive, realistic, and interactive learning environments and personalized learning experiences. Additionally, they could identify, monitor, and analyze students' characteristics, performance, preferences, and motivational, cognitive, and psychological states. These systems could also adapt the learning content, resources, activities, and assessment according to students' needs and make suitable recommendations. Their ability to offer tailored and real-time feedback, guidance, analytics, and evaluation was highlighted. Additionally, it was revealed that these systems offer meaningful learning experiences and enhance cognitive, affective, psychomotor, and embodied learning through self-directed learning, collaborative learning, personalized learning, and experiential learning approaches. Regarding learning benefits, students who learnt using this combination demonstrated increased engagement, motivation, confidence, immersion, and enjoyment. The students also reported better learning outcomes and academic performance, enhanced knowledge and skills, and improved information understanding and recall. This study also presents the main topics and areas examined, goes over the existing challenges, and suggests future research directions. Finally, the study emphasizes the importance of capitalizing on both human intelligence and machine intelligence to support students, meet their needs, and provide them with quality education and lifelong learning opportunities.

**Keywords:** artificial intelligence; ai; intelligent tutoring systems; intelligent tutors; virtual assistants; chatbots; augmented reality; virtual reality; extended reality; metaverse; review; bibliometric analysis



Academic Editor: Rui Araújo

Received: 5 February 2025
Revised: 12 March 2025
Accepted: 13 March 2025
Published: 15 March 2025

**Citation:** Lampropoulos, G. Augmented Reality, Virtual Reality, and Intelligent Tutoring Systems in Education and Training: A Systematic Literature Review. *Appl. Sci.* **2025**, *15*, 3223. https://doi.org/10.3390/app15063223



## 1. Introduction

Research into the use of artificial intelligence in education is rapidly increasing as there are several benefits that can be yielded through its integration in teaching and learning practices [1]. Nonetheless, there are challenges and issues that need to be addressed, such as ethical considerations, security and privacy issues, algorithmic bias concerns, technical limitations, etc. [2,3]. Therefore, emphasis is being put on addressing these issues and on effectively integrating artificial intelligence tools and solutions to provide students with more adaptive and personalized learning experiences which can lead to increased learning outcomes [4,5]. Adaptive learning focuses on automatically providing interactive and dynamic content, feedback, and experiences that are modified according to the knowledge, preferences, and skills of learners [6–8]. Personalized learning puts emphasis on customizing the learning experience based on each learner's preferences and needs to aid them in achieving their learning goals [9,10].

To tailor instructional strategies, activities, and material to each learner, focus is placed on the development and integration of intelligent tutoring systems [11,12]. Intelligent tutoring systems can identify, track, and monitor learners' cognitive, behavioral, and psychological states [13,14]. Additionally, intelligent tutoring systems aid students in acquiring domain-specific, cognitive, and metacognitive knowledge through their complex computational models [15,16] and offer student-centered, self-paced, interactive, and customizable learning experiences [17]. The computational models used within intelligent tutoring systems include various knowledge types, models, and components and focus on learners' cognitive, emotional, and motivational states to offer effective technology-enhanced learning environments [12,18,19].

Intelligent tutoring systems aim to offer learners learning experiences that surpass those offered by a sophisticated human tutor by adapting to the unique characteristics and traits of each learner [20,21]. In well-defined domains, intelligent tutoring systems can increase students' learning outcomes [22] and perform almost as effectively as human tutors [23] while they are still being outperformed by human tutors in ill-defined domains [24]. As a result, their integration in educational settings in both K-12 education and higher education can yield positive learning outcomes whether they are used as the primary or supplementary method of instructional delivery [15,16,18,25]. Yet, there still remain several open challenges related to the development and integration of intelligent tutoring systems that need to be examined and addressed [19].

In addition to more personalized learning experiences, students are also seeking to be engaged in and learn within more immersive and interactive learning environments [26,27]. Extended reality technologies are being more widely adopted and used in educational settings to offer learners such environments and experiences [28]. Due to the benefits that they can bring in teaching and learning, research into the use of augmented reality [29] and virtual reality [30] as well as the integration of artificial intelligence in extended reality [31] in education is increasing. Specifically, in the context of education, augmented reality focuses on embedding virtual information that learners can perceive through their senses in their physical environment; thus, enriching the way in which they perceive, interact with, and communicate with their surroundings and digital content [32–36]. Furthermore, virtual reality focuses on fully immersing learners in virtual reality environments that are characterized by high levels of realism, interaction, and immersion and simulating learners' physical presence within them [37–39]. Therefore, virtual reality technology focuses on creating an "all-inclusive, sensory illusion of being present in other environments" [40] that integrate social and psychological aspects so that they can be perceived as real [41].

The integration of intelligent tutoring systems within augmented reality and virtual reality environments shows great potential to improve the educational domain [42]. Although there have been several review and meta-analysis studies that have explored the individual use of augmented reality [43–47], virtual reality [28,48–50], and intelligent tutoring systems [11,15,25,51] in education, to the best of our knowledge, there has not been any systematic literature review study that has focused on the integration of intelligent tutoring systems in extended reality environments. As these technologies are rapidly advancing and since their combination presents several benefits and new opportunities, it is important to examine their convergence, as recent studies have shown [31]. Therefore, this study aims to explore the use of intelligent tutoring systems within augmented reality and virtual reality environments. Therefore, it carries out a systematic literature review, a content analysis, and a bibliometric and mapping analysis of the existing literature. The main research questions that drive this study are as follows: "What are the main outcomes of integrating and using intelligent tutoring systems in extended reality environments?", "What are the main characteristics and distributions of studies relevant to the topic?", "What are the main focus areas, topics, and themes examined in the literature?", and "What is the current state of the art regarding the use of intelligent tutoring systems within extended reality environments?". This study distinguishes itself from previous systematic literature review studies that have focused solely on augmented reality, virtual reality, or the metaverse in education by focusing on and examining their use in combination with intelligent tutoring systems. Additionally, this study combines the approaches of a systematic literature review and a content analysis, as well as of a bibliometric and scientific mapping study. This study contributes to the existing literature by offering an in-depth analysis of relevant to the topic documents and synthesizing their outcomes and findings. The study also offers a content analysis of the relevant studies to identify key aspects in the use of intelligent tutoring systems in extended reality environments. Additionally, the study contributes through its bibliometric analysis and scientific mapping of the documents to identifying emerging themes, limitations, and future research directions. Therefore, the study presents the methodology used and describes all steps taken to prepare the document collection (Section 2) and showcases the analysis and results (Section 3). In Section 4, the outcomes are further discussed, and conclusive remarks are offered in Section 5.

## 2. Materials and Methods

This study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [52] guidelines to report the identification and processing of the documents which comprised the document collection examined in this study. Specifically, this approach was followed due to its rigor, to provide transparency in the processing steps, and to increase the reproducibility of the data generated. Additionally, the study followed specific guidelines and principles defined in the literature to effectively carry out a systematic content analysis and to conduct an in-depth bibliometric analysis and scientific mapping of the existing documents [53–55]. This approach is deemed suitable to thoroughly examine current topics [56]. The content analysis was manually carried out, but for the bibliometric analysis and mapping of the existing literature, specialized tools, such as Bibliometrix [55] and VOSviewer [57], were used. To obtain a better understanding of the topics defined within the collection, topic modeling was conducted using Latent Dirichlet Allocation (LDA), which is a probabilistic Bayesian model characterized by its three-level hierarchical structure [58].

Furthermore, the document identification and collection processes targeted Scopus and Web of Science (WoS) databases due to their being widely used in similar studies, rigor, quality of documents, and their relevancy to the topic [59,60]. Additionally, the specific databases were selected due to the data they generate being used in the tools adopted in this study (e.g., Bibliometrix) without requiring any manual modification, thus further improving the reproducibility and transparency of the study. Therefore, the use of only two databases can be regarded as a limitation of this study. As the study focused on the use of extended reality technologies and intelligent tutoring systems, related keywords were identified and used to search for relevant to the topic documents. Specifically, the following query was used to identify relevant documents in Scopus and WoS: ("intelligent tutoring system" OR "intelligent tutoring systems" OR "intelligent tutor" OR "intelligent tutors") AND ("AR" OR "VR" OR "augmented reality" OR "virtual reality" OR "metaverse" OR "extended reality" OR "mixed reality"). It should be noted that more specialized keywords were avoided to provide a more general and thorough representation of the literature without giving explicit directions.

The final query ran on the title, abstract, and keywords of the documents in January 2025, so the related outcomes are representative of the documents published until December 2024. However, only documents that were published in English were considered. No more limitations were set when searching for documents. However, apart from the initial search for relevant documents, the inclusion criterion set for a study to be included was for it to involve the use of intelligent tutoring systems within extended reality technologies and the metaverse. To ensure that all relevant studies were included, no further exclusion criteria were specified. During the initial stages of the document eligibility assessment, emphasis was placed on the document title and abstract to determine whether they were in line with and met the inclusion criterion set. Afterwards, during the screening process, the full-text of the documents was examined to determine whether or not a study was relevant and met the inclusion criterion. Hence, studies that did not meet the specific requirement during the different stages of the eligibility assessment were deemed out of scope and were removed.

The detailed process followed to identify and process the related documents to create the document collection that is examined in this study is presented in Figure 1. Initially, 403 relevant documents were identified (Scopus: 317 and WoS: 86), out of which 71 were duplicates and were removed. The remaining 332 documents were manually processed and assessed for eligibility based on their title and abstract. In total, 181 did not meet the inclusion criterion and were removed and 29 documents were removed as they were proceedings books and not distinct studies. Thereafter, the full text of the remaining 122 documents was searched for and successfully retrieved for all documents. Of the 122 documents, 70 were deemed out of scope as they did not meet the inclusion criterion and 20 were removed as they were published prior to 2015. The decision to remove documents prior to 2015 was based on the scope of the study, which aimed to present relevant to the topic studies of the last decade, that is, 2015–2024. Therefore, the document collection examined in this study consisted of 32 documents.

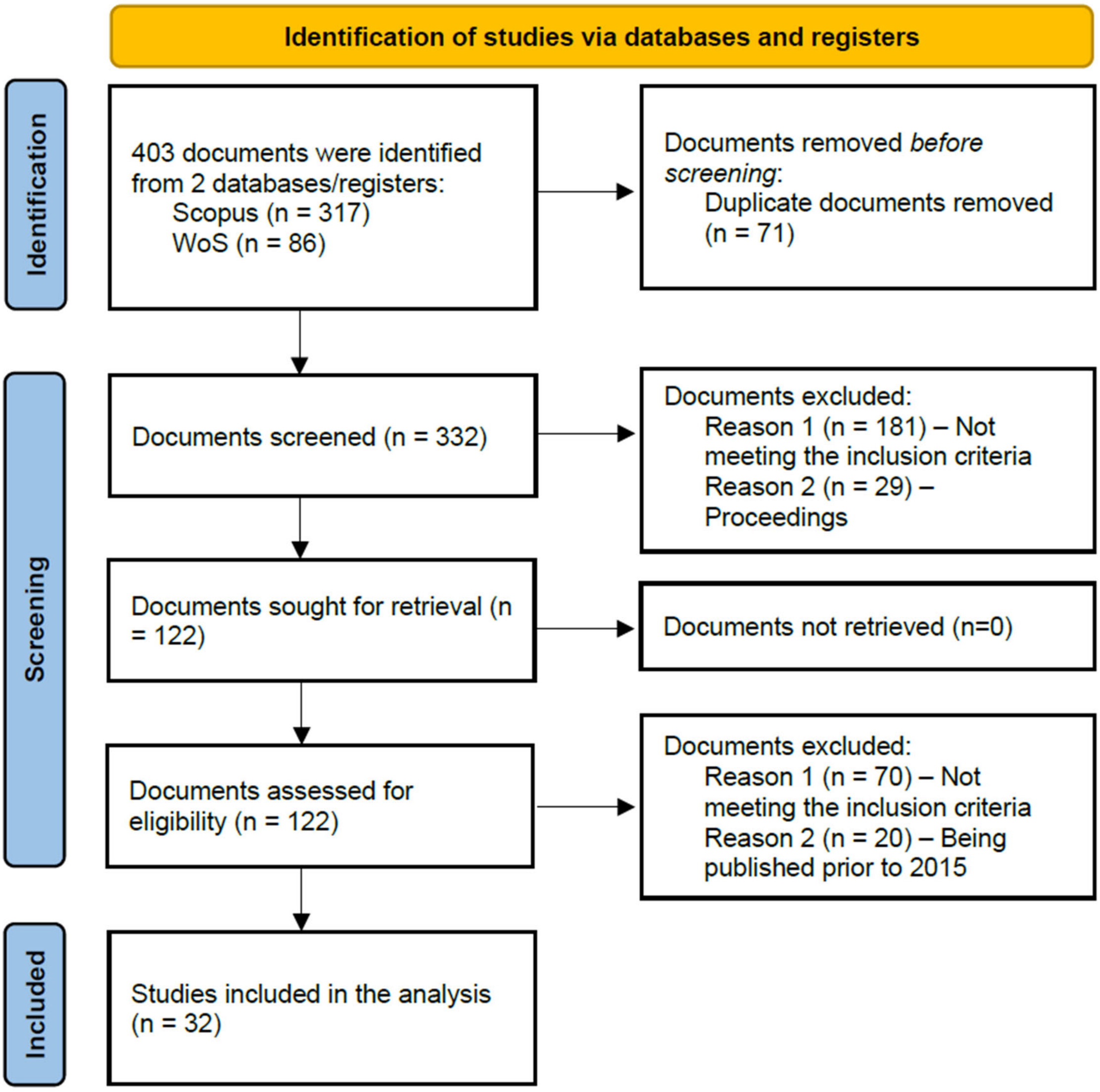


**Figure 1.** PRISMA flowchart.

## 3. Result Analysis

To provide an overview regarding the integration of intelligent tutoring systems within augmented reality and virtual reality environments, studies of all types were examined. Following the approach presented in other relevant systematic review studies [28,61], the 34 documents, as can be seen in Figure 2, were categorized into the following: (i) Theoretical and Review studies ($n$ = 9, 28.1%); (ii) Proposal and Showcase studies ($n$ = 6, 18.8%); and (iii) Experimental and Case studies ($n$ = 17, 53.1%). Specifically, Theoretical and Review studies involved studies that had contributed theoretical knowledge, frameworks, and guidelines to the field; Proposal and Showcase studies involved studies that presented prototype applications and systems but did not apply them in educational settings; and Experimental and Case studies involved studies that integrated applications and systems in educational contexts and evaluated their impact.

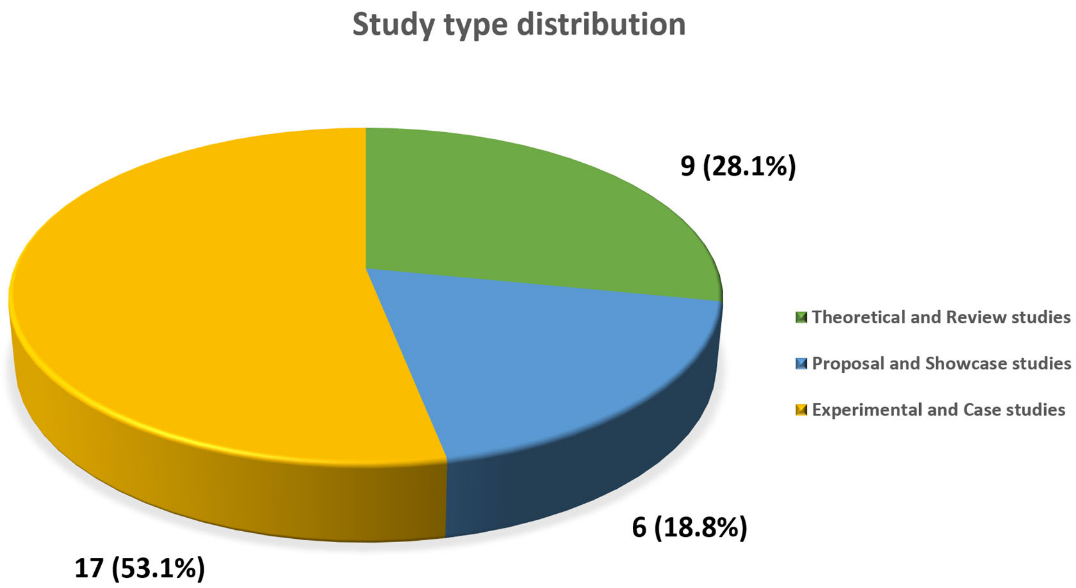


**Figure 2.** Document distribution according to type.

Moreover, the analysis of the documents goes over the characteristics of the complete document collection and presents a brief overview of the Theoretical and Review studies as well as of the Proposal and Showcase studies. Additionally, this study provides an overview of the Experimental and Case studies and further examines them through content analysis. Finally, it explores the main topics and themes within the document collection.

### *3.1. Document Collection Analysis*

This study examines 32 documents that focused on the use of intelligent tutoring systems within augmented reality and virtual reality environments. As can be seen in Table 1, the documents were published during the period of 2015–2024 in 29 different sources by 114 authors from 19 countries. Most documents were published as Journal articles ($n$ = 16), followed by Conference/Proceedings papers ($n$ = 13) and Book chapters ($n$ = 3). Among the sources, *Computers & Graphics* ($n$ = 2), *Education and Information Technologies* ($n$ = 2), and *International Journal of Artificial Intelligence in Education* ($n$ = 2) had the most documents that were relevant to the field, while the remaining 26 sources had each published a single relevant document. The documents were written by 4.03 co-authors on average and only two documents were single-authored. Additionally, the documents displayed a 25.38% annual growth rate, received 25.38 citations on average, and had an average age of 4.03 years. Finally, collaborations among countries were observed with the international co-authorship rate being 21.88%.

Based on Table 2, most documents were published in 2023 ($n$ = 8), followed by those published in 2024 ($n$ = 6) and 2018 ($n$ = 5). These outcomes highlight the steady progress of the field and it receiving more emphasis when related technologies present significant advancements. Given the number of citable years and the mean total citations per year and document, it is evident that the initially published documents have set the foundations for this field of study to advance.

**Table 1.** Information regarding the document collection.

| Description | Results | Description | Results |
|---|---|---|---|
| **Main information about data** | | **Document types** | |
| Timespan | 2015:2024 | Journal Article | 16 |
| Sources (Journals, Books, etc.) | 29 | Book Chapter | 3 |
| Documents | 32 | Conference/Proceedings Paper | 13 |
| Annual Growth Rate % | 22.03 | **Authors** | |
| Document Average Age | 4.03 | Authors | 114 |
| Average Citations per Document | 25.38 | Authors of Single-Authored Docs | 2 |
| References | 1223 | **Author collaboration** | |
| **Document contents** | | Single-Authored Docs | 2 |
| Keywords Plus (ID) | 144 | Co-Authors per Doc | 4.03 |
| Author's Keywords (DE) | 103 | International Co-Authorships % | 21.88 |

**Table 2.** Annual scientific production and citations.

| Year | MeanTCperDoc | $n$ | MeanTCperYear | CitableYears |
|---|---|---|---|---|
| 2015 | 202 | 1 | 18.36 | 11 |
| 2017 | 120 | 3 | 13.33 | 9 |
| 2018 | 25.6 | 5 | 3.2 | 8 |
| 2019 | 8 | 1 | 1.14 | 7 |
| 2020 | 14.67 | 3 | 2.44 | 6 |
| 2021 | 6 | 2 | 1.2 | 5 |
| 2022 | 7.67 | 3 | 1.92 | 4 |
| 2023 | 4 | 8 | 1.33 | 3 |
| 2024 | 0.5 | 6 | 0.25 | 2 |

Although the 32 documents were written by 114 authors, most of them contributed to 1 document ($n$ = 103 documents, 90.4%) while only a few contributed to either 2 ($n$ = 7 documents, 6.1%) or 3 ($n$ = 4 documents, 3.5%) documents. When looking at the countries of the authors, the corresponding author's country was considered. However, in cases where a corresponding author was not clearly specified, the country of the first author was taken into account. Of the 18 countries, those that published two or more documents are presented in Table 3. Specifically, the United States ($n$ = 5) had the most published documents and presented the highest intra-country (SCP) collaboration. Australia, India, Spain, and Switzerland each published three relevant to the topic documents, while Germany published two relevant documents. The remaining 13 countries each contributed one document. Additionally, Figure 3 presents the distribution of studies based on the country and category. Based on the outcomes, India ($n$ = 2) and Germany ($n$ = 2) contributed the most Theoretical and Review studies, Spain ($n$ = 2) contributed the most Proposal and Showcase studies, and the United States ($n$ = 4) and Switzerland ($n$ = 3) contributed the most Experimental and Case studies. Finally, when looking at collaborations among the countries, six clusters of collaborations emerged, as can be seen in Figure 4. The specific clusters are as follows: Red cluster—Australia, New Zealand, and the United States; Green cluster—Mexico and Spain; Purple cluster—China and Switzerland; Blue cluster—Germany and Thailand; Brown cluster—France and Italy; and Orange cluster—India and the United Arab Emirates. These outcomes highlight the global interest in this field of study, its multidisciplinary nature, and the need to establish more international collaborations to further advance it.

**Table 3.** Countries with the most published documents on the topic.

| Country | Documents | SCP | MCP | Freq. | MCP_Ratio |
|---|---|---|---|---|---|
| United States | 5 | 4 | 1 | 0.156 | 0.2 |
| Australia | 3 | 2 | 1 | 0.094 | 0.333 |
| India | 3 | 2 | 1 | 0.094 | 0.333 |
| Spain | 3 | 2 | 1 | 0.094 | 0.333 |
| Switzerland | 3 | 2 | 1 | 0.094 | 0.333 |
| Germany | 2 | 2 | 0 | 0.063 | 0 |

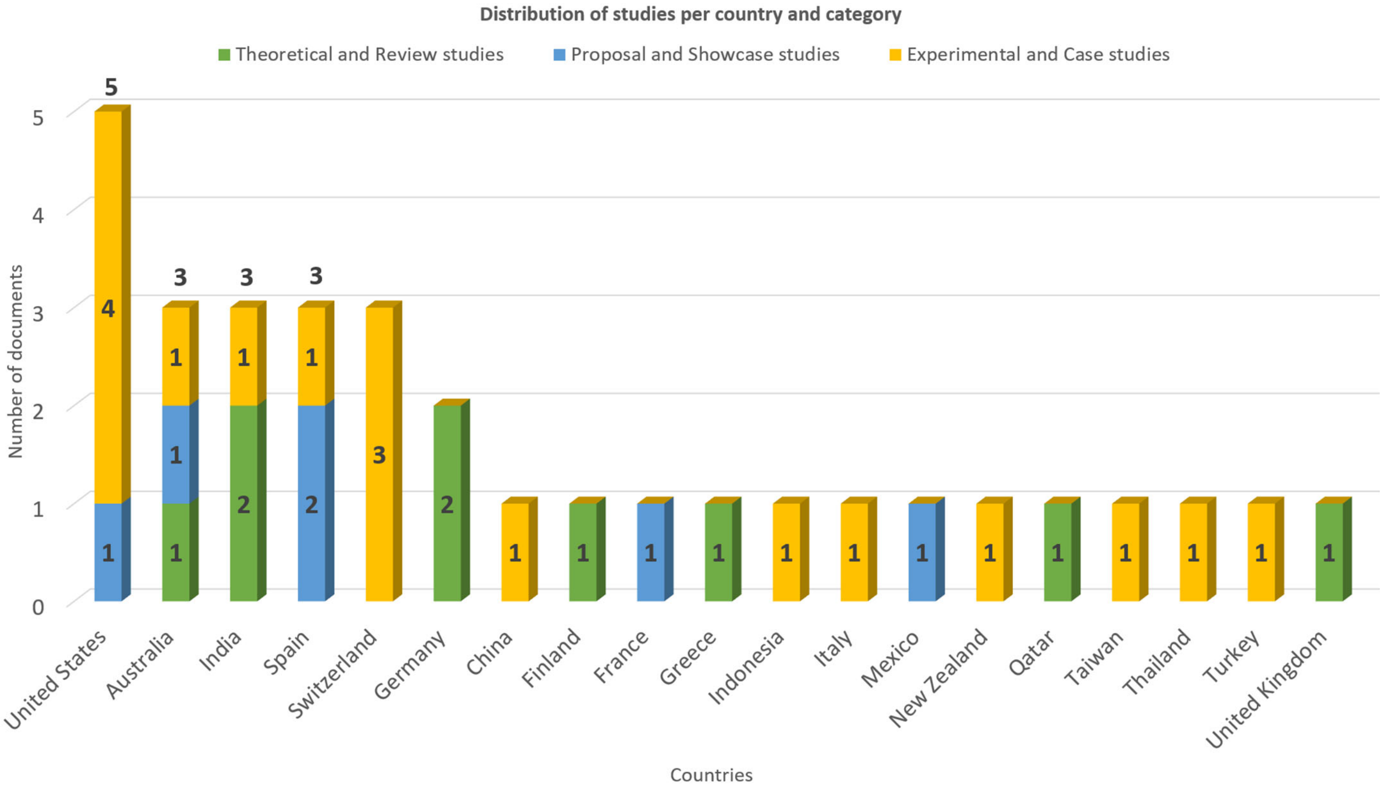


**Figure 3.** Distribution of studies per country and category.

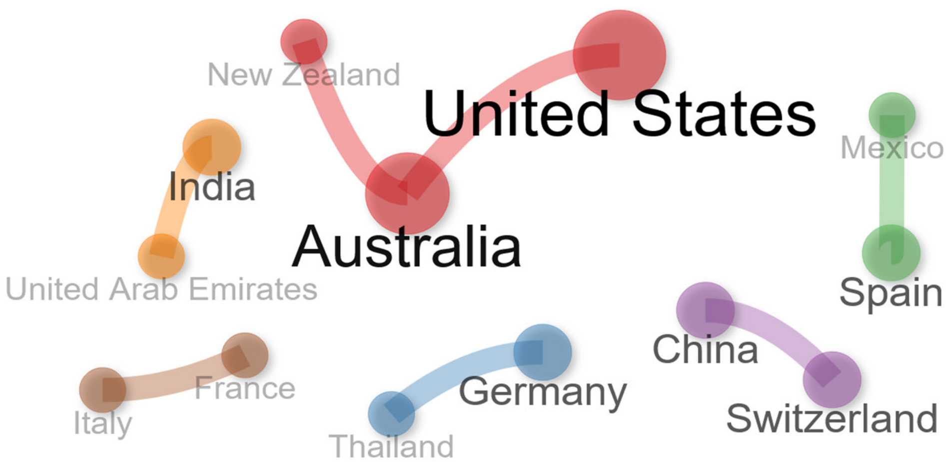


**Figure 4.** Country collaboration network.

### 3.2. Theoretical and Review Study Analysis

Of the 32 studies, 9 were categorized as Theoretical and Review studies [42,62–69]. These studies have contributed to the field through the exploration of the topic and the development of frameworks, architectures, and guidelines. However, these studies did not involve the development and presentation of an application or system, nor did they involve the conducting of a case study within educational settings.

Lampropoulos [42] explored the impact of combining augmented reality with artificial intelligence to create immersive intelligent tutoring systems. Specifically, the study presented the integration of these technologies in educational settings and commented upon the potential that their combination can bring about in teaching and learning practices. Finally, the study highlighted the ability of such systems to consider learners' characteristics, preferences, as well as their motivational, cognitive, and psychological states and to be applied across educational levels. Balakrishnan et al. [62] focused on integrating deep learning techniques into augmented reality and virtual reality experiences to create effective intelligent tutoring systems that aid students in surgical training and assessment. They highlighted personalization, high realism, and real-time feedback as integral parts of such systems. The study also discussed the benefits and challenges of integrating deep learning techniques to create adaptive training experiences and presented examples of intelligent tutoring systems that were successfully developed and introduced in the field of surgical training. Finally, the study commented upon the rise of robotics and data-driven initiatives to offer tailored training programs to increase the effectiveness of skill acquisition and development.

Häfner et al. [63,64] presented a framework for creating intelligent virtual reality tutoring systems in the context of engineering education. Their approach used three core modules, capitalized on the semantic web, and focused on reducing the high cost of setting up and maintaining virtual reality environments. Specifically, they stated that by using the semantic web, it is feasible to use its reasoning capabilities and heterogeneous knowledge integration to facilitate virtual reality training material creation, maintenance, and update. Rohil et al. [65] showcased their proposed architecture to effectively combine intelligent tutoring systems with augmented reality. Emphasis was put on the analysis of existing augmented reality and intelligent tutoring systems and the potential benefits that can be yielded through their combination. They highlighted the need to focus on extensibility, interoperability, low latency, and low response time to enable such systems to be effectively used in education. Finally, they emphasized real-time content and information generation.

Alam and Mohanty [66] explored the convergence of various educational technologies. In their study, they commented upon the capabilities of artificial intelligence and its potential to be used within augmented reality and virtual reality environments to create effective intelligent tutoring systems. They also highlighted that through this approach, students' adaptive and personalized learning can be enriched. Finally, they commented upon the need to develop new educational frameworks that capitalize on such intelligent tutoring systems. Korhonen et al. [67] presented a framework to develop artificial intelligence-based immersive learning to support learners' hard-skills training. Specifically, they focused on integrating intelligent tutoring systems into virtual reality environments to create virtual reality-native intelligent tutors. The study highlighted the need to focus on learners' cognition and on increasing their bodily engagement by supporting embodied learning. Additionally, the ability of such systems to provide effective simulation environments that support scaffolding, real-time feedback, and task sequencing was highly regarded.

Huang et al. [68] focused on the design aspects associated with the creation of humanoid intelligent agents. Specifically, they examined and compared different intelligent agents that can interact with both virtual and real surroundings to identify key design elements through the lens of augmented reality technology and smart glasses. Their framework considered different aspects including agents' intelligence, appearance, responses, and behavior. Based on their findings, the main categories of intelligent agents were chatbot agents, intelligent tutors, game characters, and simulation agents. Finally, they highlighted the importance of natural language processing, user-centered services, eye-tracking, and multimodal interactivities. Herbert et al. [69] also focused on the design considerations associated with the combination of intelligent tutors with augmented reality. They highlighted the need to adapt training content and activities to each learners' needs and commented upon how the convergence of these technologies can result in the creation of adaptive and personalized learning experiences. Finally, they provided guidelines on how to develop augmented reality intelligent tutoring systems that can constitute effective cognitive support tools which can support psychomotor training.

### 3.3. Proposal and Showcase Studies Analysis

A total of six studies were categorized as Proposal and Showcase studies [70–75]. These studies, in addition to theoretical contributions, have also presented a prototype of a system or application. However, these studies have not applied their system within educational settings yet.

Ruiz et al. [70] went over the design and development of their proposed author tool and intelligent tutor which focused on integrating intelligent tutoring systems within virtual reality and 360-degree educational environments. Their study presented a related project and discussed in detail the specifications of their proposed tool and its aspects which worked within the Unity game engine. Specifically, they showcased the different stages of the project, presented the author tool, and analyzed the learning experiences and scenarios that it offers. Thandapani et al. [71] presented an authoring tool to develop immersive intelligent tutoring systems for virtual reality experiences. Their tool provides a no-code approach to creating realistic industrial environments to aid students and educators in developing relevant skills and acquiring practical knowledge. Following the proposed authoring tool, a prototype application, which involved training scenarios on handling laser-based cutting machines, was developed and presented. Schez-Sobrino et al. [72] focused on integrating intelligent tutoring systems within augmented reality environments to support students' programming learning. Their application provided automatically generated graphic visualizations to aid both students and teachers in understanding and explaining programming concepts. The extensibility and flexibility of such applications were highly regarded.

Ahn et al. [73] explored the use of intelligent tutoring systems within virtual reality environments. They presented their prototype and evaluated it based on the views of experts. Additionally, they provided an overview of their system design and implementation and commented upon the system ability and potential to integrate and support open educational resources. Santamaría-Bonfil et al. [74] presented their virtual reality application which integrated an intelligent tutoring system to support students' learning of electrical operations. Specifically, they focused on a model that mapped students' errors to features using a bag-of-errors scheme to categorize students based on their performance. Additionally, they commented that such an approach can help identify aspects which students need further assistance with. Herbert et al. [75] presented an adaptive learning system that combines augmented reality with an intelligent tutoring system. They went over the specifications of their prototype and commented upon its use cases. To better support psychomotor learning, the specific application can be used across different interfaces, such as desktops, hand-held devices, and head-mounted displays.

### 3.4. Experimental and Case Studies Analysis

In total, 17 studies were categorized as Experimental and Case studies [76–92]. These studies involved the integration and use of relevant applications and systems within educational settings and the assessment of their impact.

Most studies of this category were published in 2023, 2022, and 2018. In terms of the extended reality technology on which more emphasis was placed, most studies focused on integrating intelligent tutoring systems within augmented reality ($n$ = 11) [77,79–82,85–88,91,92]. Of the 17 Experimental and Case studies, only 5 examined the use of intelligent tutoring systems within virtual reality environments [76,78,83,84,90], and 1 study focused on their use in mixed reality environments [89].

Emphasis was mostly placed on higher education ($n$ = 8) [76,78,82,83,85,86,90,92], followed by secondary education ($n$ = 6) [77,79,80,87–89]. To a lesser extent, studies focused on primary education ($n$ = 2) [81,84] and on other training environments ($n$ = 1) [91]. As only one study [81] focused on special education, there is a clear need for more studies to be conducted to better understand how this combination can support special education across educational levels. The wide applicability of this approach is highlighted by the number of different subjects in which it has already been applied. For example, studies looked into its use in science learning [77,80], medical education (e.g., surgery) [83,85,86], mathematics [89], physics [78], and geometry [79]. Additionally, studies explored its integration in language learning, assembly operations [87], programming [76], and network security [82]. Studies also looked into their ability to assist students' driving skills [90] and aircraft knowledge [88]. Finally, studies explored the adoption and integration of intelligent tutoring systems into augmented reality and virtual reality environments as part of teacher training [84] and of general educational competences [81].

Additionally, most studies adopted a quantitative research approach and focused on examining the impact that the integration of intelligent tutoring systems into augmented reality and virtual reality can have on students ($n$ = 12) [76–81,85–88,90,92]. To a lesser extent, studies included various education stakeholders ($n$ = 3) [82–84] in their experiments, while only one study focused on both students and teachers [89]. Finally, one study [91] looked into the impact of this combination on learners' training within the workforce.

Furthermore, the related studies and their outcomes are briefly presented. Ateş [77] compared traditional methods of teaching with an intelligent tutoring system within augmented reality in the context of science education. The system provided students with personalized learning experiences, adaptive learning routes, and tailored feedback. The outcomes highlighted the ability of such systems to improve students' motivation, confidence, enthusiasm, and engagement. Finally, it was concluded that this approach can significantly improve students' learning outcomes in science education. Sarshartehrani et al. [76] explored the use of artificial intelligence within virtual reality to enhance learners' engagement. Their study focused on providing students with personalized learning pathways and an intelligent tutoring system. Their outcomes revealed that this approach can support and improve online education and lifelong learning. Finally, they quoted the gradual shift toward more personalized and interactive e-learning solutions. Yasin and Utomo [80] examined students' learning motivation using an augmented reality system that integrated an intelligent tutoring system. The system was developed using the ADDIE method and provided students with personalized and interactive learning. Based on their findings, this approach was proven to be an effective medium to enhance students' motivation and understanding.

Uriarte-Portillo et al. [79] assessed students' learning motivation by comparing an augmented reality application with an augmented reality application that also integrated an intelligent tutoring system. Based on their results, both approaches improved students' motivation; however, when learning through intelligent tutoring systems, students' learning gains were further enhanced. Hence, it was concluded that the integration of intelligent tutoring systems within augmented reality environments can effectively aid students' learning and understanding of difficult topics. Highlighting the need to offer students effective guidelines when interacting with virtual environments, Bezanson et al. [78] explored the use of intelligent tutoring systems within virtual reality environments. The ability of the system to offer students prompt and tailored feedback in various modalities was highly regarded. The outcomes of this study further validated the potential of this approach to create immersive and engaging learning experiences. Herbert et al. [82] focused on improving students' network security training through the use of intelligent tutoring systems and augmented reality. When using the augmented reality systems, the feedback that the students received in the various tasks examined differed as the amount of information they received gradually decreased. Students presented increased engagement and skills, and the outcomes further confirmed that as students' knowledge and understanding increase, the instructional mechanisms become redundant.

Moreover, Vannaprathip et al. [83] developed a virtual reality system that integrated intelligent tutoring to aid in teaching decision-making during surgical operations. Their findings revealed that the intelligent tutor interventions were significantly better than the human tutor ones; thus, highlighting the potential to create effective virtual tutors. Ahuja et al. [81] explored the use of an intelligent tutoring system that capitalized on augmented reality content. Their system focused on identifying students with learning disabilities. Through their comparisons, augmented reality-based learning through intelligent tutoring systems emerged as an effective approach that could yield several benefits, such as enhancing students' cognitive skills, motivation, interaction, enjoyment, and short-term memory. Delamarre et al. [84] presented and examined a virtual reality training tool for teachers. The specific tool aimed at allowing teachers to practice their behavior management while receiving real-time feedback. The modular architecture of the system enabled additional intelligent tutoring capabilities to be integrated. The results highlighted the potential of such systems to enable teachers to efficiently practice and improve their skills while simultaneously being easy to use and learn.

Ropelato et al. [86] examined the use of intelligent tutoring systems within augmented reality environments to support learners' microsurgical skills. The outcomes of the study presented the potential of augmented reality simulations to improve learners' direct and long-term skills when enriched with intelligent tutoring systems to provide tailored experiences, tasks, and feedback. Menozzi et al. [85] also focused on improving learners' surgical skills. In their study, they used augmented reality simulations as well as an intelligent tutoring system. Both methods significantly enhanced students' motor skills. However, after the initial days of training, students' performance improvement slowed down, with the students that were learning using the intelligent tutoring system intervention presenting steeper training progress. The study showcased that these methods can support the educational process and commented upon the technical challenges that need to be addressed.

Wang et al. [87] focused on exploring the modeling and verification aspects associated with an intelligent tutoring system that integrated augmented reality, speech recognition, and text-to-speech. Their system targeted both students and teachers. Their outcomes highlighted that their approach resulted in users achieving better learning performance and operating the system more effectively. Wei et al. [88] developed and applied an augmented reality simulation to enhance students' authentic learning experience. Their simulation integrated an intelligent tutoring system to more effectively guide the learning process. Their results showcased that this combination can improve students' immersion and learning motivation, offer them realistic learning experiences, and enhance their learning outcomes. Holstein et al. [89] examined the use of a mixed reality application that integrated intelligent tutoring systems and real-time analytics to support both students and teachers. The study highlighted the importance of teachers having real-time access to students' behavior, metacognition, and learning can enhance both theirs and their students' performance and experience. Specifically, by offering teachers real-time analytics, the gap between the learning outcomes across students is decreased as students' learning is improved. Finally, the study commented upon the ability of such systems to capitalize on both human and machine intelligence to support students.

In their study, Ropelato et al. [90] looked into improving users' driving skills through the use of immersive virtual reality simulators that included an intelligent tutoring system. Their findings presented the capabilities of this approach to provide users with realistic, immersive, and interactive experiences to cultivate their skills. Additionally, it was revealed that such simulations can provide experiences that are in line with those of the real world and can be perceived as real by users. Longo et al. [91] examined the use of intelligent tutoring systems and augmented reality environments in workplace training. Specifically, they focused on improving users' assembly and operation knowledge and skills. Their results highlighted the ability of this approach to effectively support learners even in the workplace as its use significantly affected users' learning curve and abilities. Westerfield et al. [92] examined the combination of intelligent tutoring systems with augmented reality to aid learners' assembly knowledge and skills. Their system offered realistic and hands-on training and learners who used it presented increased test scores and completed tasks faster. Hence, it was concluded that when using intelligent augmented reality tutors, students' learning outcomes are further enhanced when compared to using traditional augmented reality training.

## 4. Discussion

Intelligent tutoring systems, augmented reality and virtual reality are increasingly being used in education. Therefore, studies have put emphasis on examining how recent technologies, such as the metaverse and extended reality technologies, are being adopted and used in education [93]. Moreover, studies have highlighted the educational benefits that can be yielded through the adoption of intelligent tutoring systems [11,15,25,51], augmented reality [43–47], and virtual reality [28,48–50] in teaching and learning activities in both traditional and vocational education [94]. The integration of intelligent tutoring systems into augmented reality and virtual reality environments can result in the development of social and affective entities that can support the education process, promote collaborative learning and self-directed learning, and enhance students' learning outcomes [31]. Hence, extended reality technologies not only can lead to increased learning outcomes [95] but cam also aid in achieving the main goal of intelligent tutoring systems which is to offer tailored learning experiences that adapt to learners at a fine-grained level and surpass that of a sophisticated human tutor [20,21].

### *4.1. Synthesis of Outcomes*

The outcomes of the studies examined highlighted that by combining augmented reality and virtual reality technologies with intelligent tutoring systems, effective virtual tutors [83], immersive and engaging environments [78], and realistic simulations that offer hands-on experiences [62,90,92] can be created. These systems are flexible and extensible [70,72] and can use various interfaces [75]. Additionally, these immersive and intelligent systems can identify students' preferences, learning styles, and performance [74,81,96], provide predictive and diagnostic solutions [97], consider learners' motivational, cognitive, and psychological states and traits [42,98], support open educational resources, and increase accessibility [73].

Additionally, the findings highlighted the ability of this approach to offer interactive, personalized, and adaptive learning experiences [42,62,66,69,76,77,80,86], support scaffolding, and provide tailored and real-time feedback and assessment [24,62,64,67,77,78,86]. By integrating intelligent tutoring systems into augmented reality and virtual reality environments, students' motivation [42,77,79,80,88], confidence [77], immersion and engagement [77,88,90], as well as enthusiasm and enjoyment [77,81], can be enhanced. Additionally, students, who learnt through this approach and such systems, demonstrated increased learning outcomes and performance [42,77,79,81,87,88,92] and improved learning gains, knowledge, skills, and understanding [79–82,86,90,91] compared to those who used traditional methods of learning. Besides the benefits it can yield for students, this combination can also effectively support teachers and enable them to perform better, focus on their students, and be more actively engaged in the educational process [84,87,89]. Additionally, these technologies and their combination can be used across educational levels [42], support face-to-face, online, and lifelong learning [76], improve psychomotor, cognitive, affective, and embodied learning [67,69,75,85], and enrich workplace training [91]. However, to reap the benefits of this approach, there are challenges that need to be addressed, such as data quality and availability, data and model transparency, security and privacy issues, ethical and moral considerations, peer interaction and student–teacher interaction and communication, technical challenges, hardware and software limitations, teachers' digital competences, the development of material, design considerations, training programs, and algorithmic bias considerations. It is particularly important to focus on the design of such systems [68,69,99], reducing related costs [63,64], increasing their interoperability, and reducing response time and latency [65].

### *4.2. Thematic, Trend, and Topic Analysis*

In addition to the analysis of the documents presented, to better understand the main topics and themes examined in the literature, the documents' keywords were also examined. Both author's keywords and keywords plus/index keywords were used since they can effectively represent the documents' knowledge structure [100]. Specifically, the most commonly used keywords plus/index keywords were as follows: intelligent tutoring systems ($n$ = 22), augmented reality ($n$ = 17), virtual reality ($n$ = 10), computer-aided instruction ($n$ = 9), artificial intelligence ($n$ = 8), education ($n$ = 6), simulation ($n$ = 6), computing education ($n$ = 5), design ($n$ = 5), human-computer interaction ($n$ = 5), immersive learning ($n$ = 5), learning systems ($n$ = 5), personalized learning ($n$ = 5), and students ($n$ = 5). While the most frequently used author's keywords were as follows: augmented reality ($n$ = 18), intelligent tutoring systems ($n$ = 18), virtual reality ($n$ = 8), artificial intelligence ($n$ = 7), human-computer interaction ($n$ = 6), training ($n$ = 6), education ($n$ = 5), personalized learning ($n$ = 4), adaptive learning ($n$ = 3), surgery ($n$ = 3), design ($n$ = 2), immersive learning ($n$ = 2), simulation ($n$ = 2), and teachers ($n$ = 2).

These outcomes were further explored through a co-occurrence network analysis using both Bibliometrix and VOSviewer. In the case of Bibliometrix, keywords plus/index keywords were used while for VOSviewer, both author's keywords and keywords plus/index keywords were used. The related networks are presented in Figures 5 and 6, respectively. Specifically, in the Bibliometrix co-occurrence network, ten clusters arose. The clusters and related keywords identified were as follows: Blue cluster ($n$ = 14 keywords)—computer-aided instruction, virtual reality, learning systems, artificial intelligence, tutoring systems, adaptive learning, education, computing education, e-learning, intelligent tutoring, personalized learning, immersive learning, learning experiences, and engineering education; Red cluster ($n$ = 3 keywords)—intelligent tutoring systems, augmented reality, and human–computer interaction; Green cluster ($n$ = 2 keywords)—teaching and learning. The following seven single-keyword clusters were also identified: architecture (Gray cluster); design (Brown cluster); simulation (Orange cluster); students (Pink cluster); surgery (Turquoise cluster); teachers (Purple cluster); and training (Lavender gray cluster).

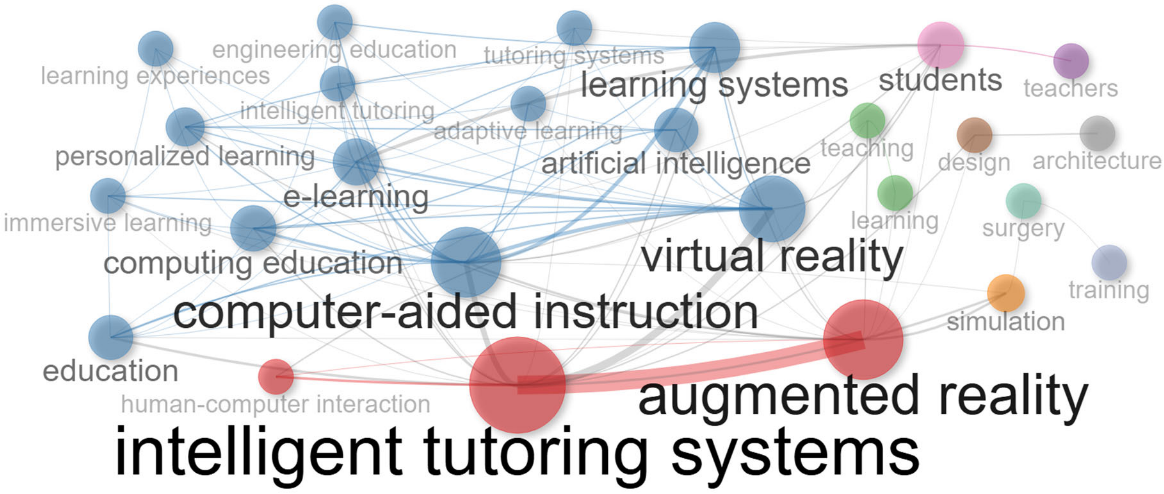


**Figure 5.** Co-occurrence network—Bibliometrix.

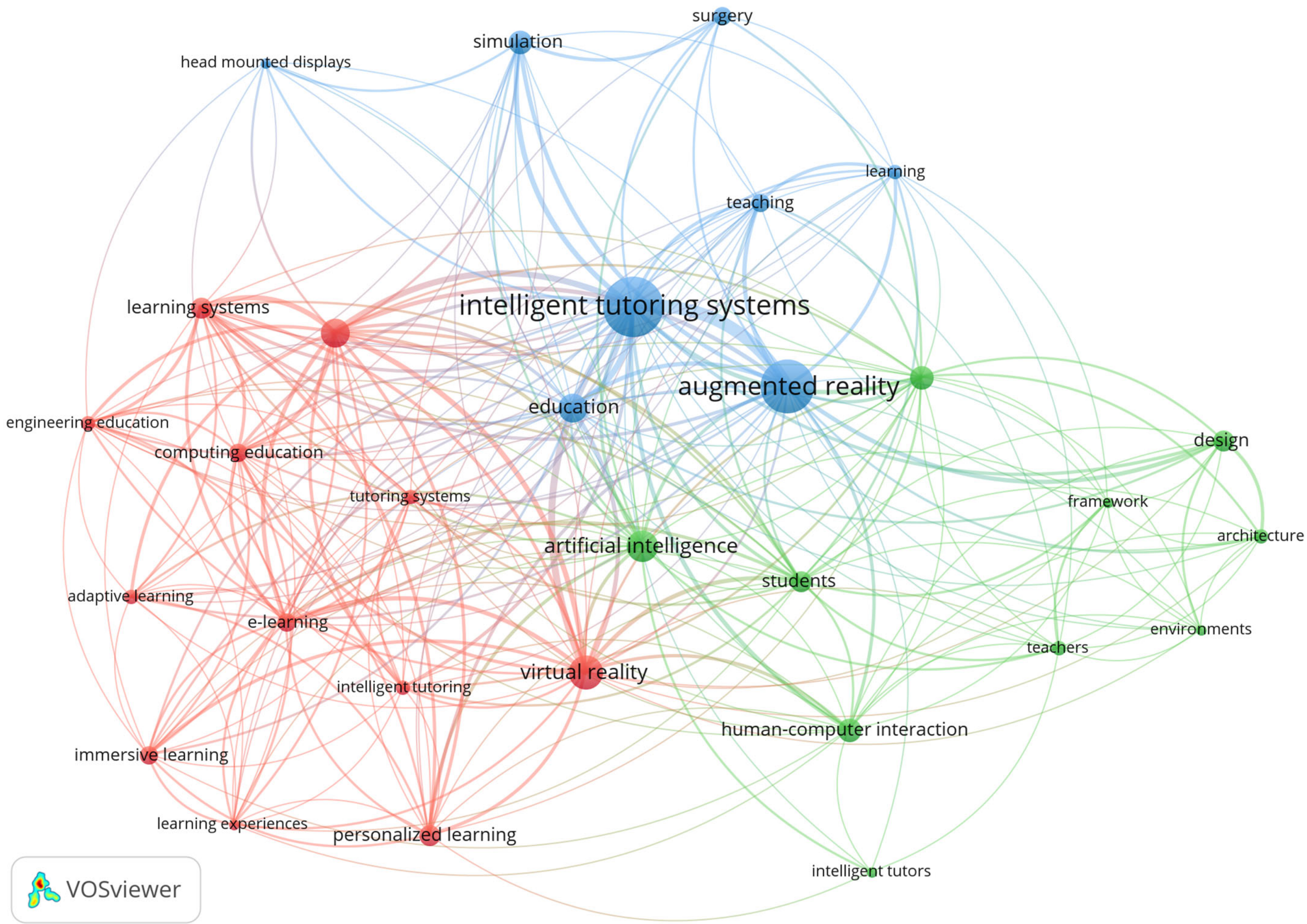


**Figure 6.** Keyword co-occurrence network—VOSviewer.

Furthermore, the co-occurrence network of VOSviewer resulted in the creation of three clusters. The first cluster (Red) was related to adaptive learning, computer-aided instruction, computing education, e-learning, engineering education, immersive learning, intelligent tutoring, learning experiences, learning systems, personalized learning, tutoring systems, and virtual reality. The second cluster (Green) was related to architecture, artificial intelligence, design, environments, framework, human-computer interaction, intelligent tutors, students, teachers, and training. The third cluster (Blue) was related to augmented reality, education, head-mounted displays, intelligent tutoring systems, learning, simulation, surgery, and teaching. Additionally, Table 4 presents the total link strength of the related keywords. Based on the outcomes, intelligent tutoring systems, augmented reality, computer-aided instruction, and virtual reality had the highest total link strength.

**Table 4.** Co-occurrence analysis—Total link strength.

| Keyword | Total Link Strength | Keyword | Total Link Strength | Keyword | Total Link Strength |
|---|---|---|---|---|---|
| intelligent tutoring systems | 90 | training | 37 | design | 22 |
| augmented reality | 76 | personalized learning | 33 | learning systems | 22 |
| computer-aided instruction | 65 | human-computer interaction | 29 | learning experiences | 21 |
| virtual reality | 64 | engineering education | 28 | teachers | 17 |
| students | 44 | simulation | 28 | architecture | 16 |
| learning systems | 43 | teaching | 28 | framework | 14 |
| artificial intelligence | 42 | immersive learning | 27 | surgery | 14 |
| e-learning | 41 | intelligent tutoring | 26 | head-mounted displays | 13 |
| education | 41 | tutoring systems | 23 | environments | 12 |
| computing education | 38 | adaptive learning | 22 | intelligent tutors | 7 |

These outcomes are also in line with the trend topics identified, which are displayed in Figure 7. Specifically, an emphasis on computer-aided instruction, computing education, and simulations can be observed. Emphasis was placed on both augmented reality and virtual reality; however, the integration of intelligent tutoring systems into extended reality technologies initially focused on augmented reality technology. Over the last few years, increased interest is observed in human-computer interaction and in design aspects and methods. Finally, the adoption and integration of this combination in educational settings is highlighted.

Moreover, the topic modeling through LDA that was based on the title and abstract of the related studies did not provide any distinct topics. However, three main areas emerged. These were related to the following: (i) Augmented Reality—augmented reality (13.431), tutoring systems (2.459), school students (1.272), artificial intelligence (0.483), and learning experiences (0.125); (ii) Virtual Reality—virtual reality (9.035), tutoring systems (0.459), artificial intelligence (0.125), learning experiences (0.125), and school students (0.125); and (iii) Artificial Intelligence—artificial intelligence (4.363), tutoring systems (2.434), learning experiences (1.642), virtual reality (1.418), and augmented reality (0.731). The topics sharing common keywords highlights, once again, their close connection and inter-relationship. Furthermore, the thematic map, presented in Figure 8, depicts 5 main themes that emerged. Specifically, (i) the Motor Theme was related to intelligent tutoring systems, augmented reality, virtual reality, artificial intelligence, and computer-aided instruction; (ii) the Basic

Theme was related to teaching, learning, teachers, and students; (iii) the Niche Theme was related to design, architecture, and frameworks, and (iv) the Emerging or Declining Themes were related to (a) medical education, surgery, training, simulation, and clinical competence and (b) intelligent tutors, intelligent systems, and intelligent agents.

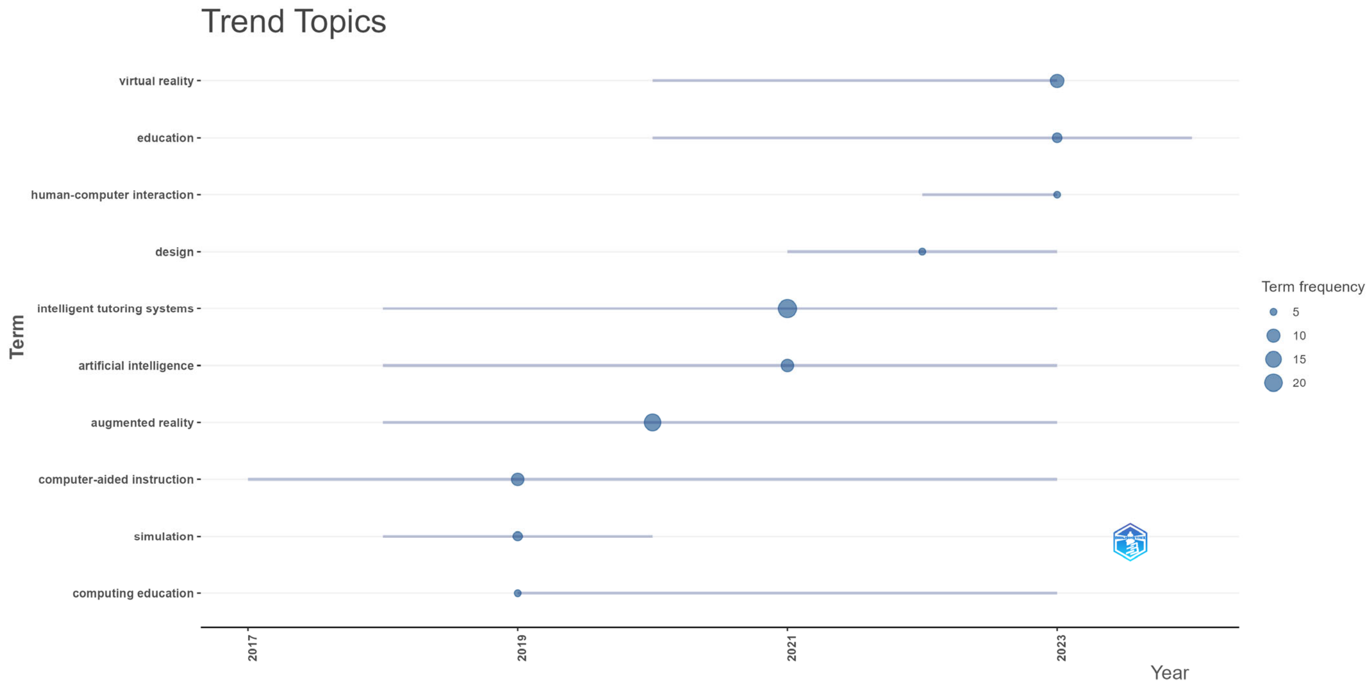


**Figure 7.** Trend topics.

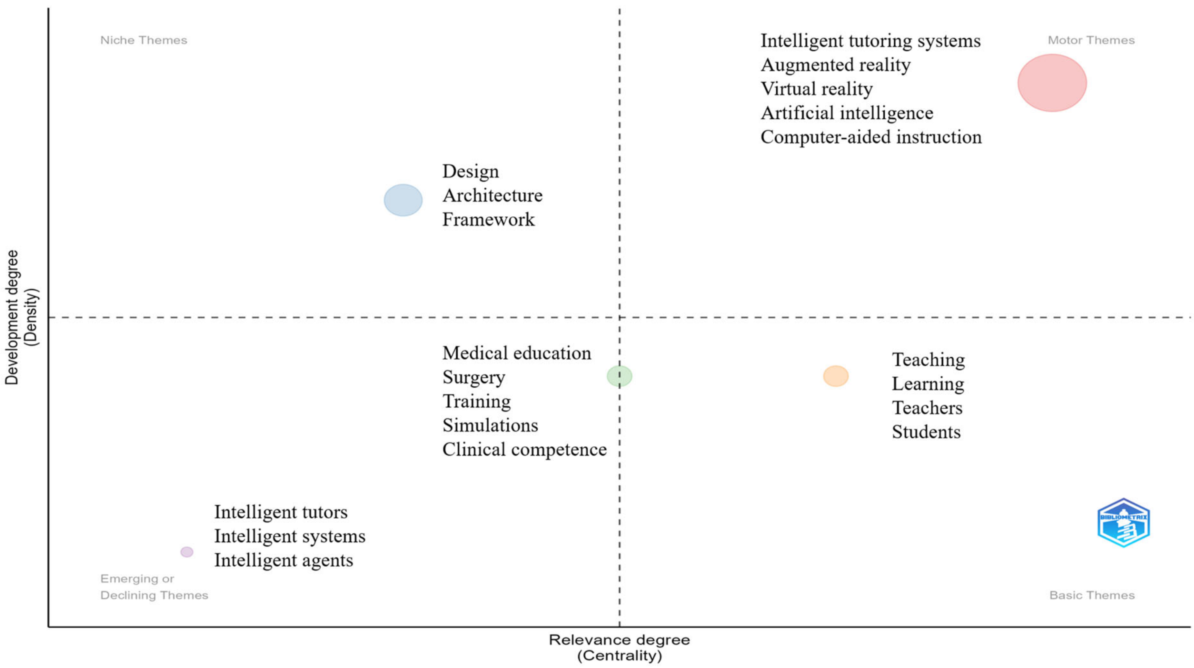


**Figure 8.** Thematic map.

## 5. Conclusions

Intelligent tutoring systems and extended reality technologies have shown great potential to transform and enrich the educational domain. This study examined the integration of intelligent tutoring systems into augmented reality and virtual reality environments through a systematic literature review following the PRISMA framework. A total of 32 relevant documents published during the period of 2015–2024 from Scopus and WoS were examined. The studies were separated into Theoretical and Review studies, Proposal and Showcase studies, and Experimental and Case studies. In addition to the analysis of the studies and their contents, this study also included a bibliometric analysis and scientific mapping of the literature, and examined the emerging topics and themes described in the literature.

The results of this study highlight the positive impact that the integration of intelligent tutoring systems into augmented reality and virtual reality can have in education. Specifically, through the combination of these technologies, effective learning environments that offer realistic, immersive, adaptive, and engaging learning experiences can be created. Learners can be engaged in hands-on learning activities within these safe virtual environments. Additionally, these interactive, virtual, and intelligent tutors offer personalized learning through the identification of, the monitoring of, and the adaptation to students' motivational, cognitive, and psychological states, characteristics, learning styles, skills, knowledge, and performance. Therefore, these systems offer real-time and tailored feedback, analytics, and assessment, provide individualized recommendations, and modify the learning content, activities, and resources according to the needs of each learner. Furthermore, these systems enhance psychomotor, cognitive, affective, and embodied learning through self-directed, collaborative, personalized, and experiential learning approaches. Due to their nature, they can be used across educational levels and in various subjects to support face-to-face, blended, and online learning and promote lifelong learning.

In terms of learning benefits, when using augmented reality and virtual reality environments enriched with intelligent tutoring systems, students' motivation, engagement, enjoyment, immersion, and confidence increased. Additionally, students that learnt through this approach demonstrated increased learning outcomes and academic achievements, improved knowledge and skills, and enhanced learning gains and understanding. This approach also effectively supported teachers during classes and enabled them to perform better by focusing more on their students, identifying their needs, adapting the material and exercises, and being more actively involved. In addition to its use in educational settings, this approach also presented great potential to support training in the workplace. As a result, this study encourages educators and trainers to adopt these technologies in their classrooms and practices and urges policymakers to provide adequate support through funding allocation and development programs, to ensure that educational institutes have the required infrastructure and equipment, and to develop and establish suitable policies, guidelines, and frameworks. Simultaneously, it encourages developers to cooperate with and involve education stakeholders throughout the design and development process to create effective and student-centered applications and platforms that are adaptable, user-friendly, and accessible to students.

Besides the challenges and issues identified in the Discussion Section, more emphasis should be placed on further examining and addressing them. Hence, future studies should focus on exploring the potential drawbacks and challenges associated with the use of intelligent tutoring systems in extended reality environments. Future studies should also focus on examining related ethical challenges and security issues associated with the use of intelligent tutoring systems and extended reality technologies in education. It is also important to identify the most suitable pedagogical approaches that can be effectively used in combination with intelligent tutoring systems as well as with augmented reality and virtual reality technologies, evaluate their effectiveness, and define the key methods and strategies to promote them. Additionally, there is a need for more case studies to be conducted that examine the effect of this approach on students when they learn through it for a prolonged time period across different settings. Emphasis should also be placed on defining standards and frameworks to effectively develop, integrate, and evaluate such systems and interventions. The influence of the virtual presence of the intelligent tutor and its characteristics should also be examined. Guidelines to effectively design such tutors and experiences should also be explored. Emphasis should also be put on how students' development, emotions, and interactions are affected. Finally, there is a need to explore teachers' competences and education stakeholders' views regarding the adoption and integration of intelligent tutoring systems and extended reality technologies in education.

As a result, the effectiveness of this approach and these technologies to offer meaningful learning experiences is highlighted. However, the importance of capitalizing on both human intelligence and machine intelligence to support students, meet their needs, and provide them with quality education and lifelong learning opportunities is emphasized.

**Funding:** This research received no external funding.

**Conflicts of Interest:** The author declares no conflicts of interest.

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