

Exploring research trends on AI-Enhanced Digital Twins for education: A bibliometric analysis

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Abstract: *This study examines research trends on AI-assisted digital twins in education through bibliometric analysis. A total of 494 publications indexed in the Scopus database between 2020 and 2025 were analyzed using VOSviewer, selecting from author citations, keyword association, bibliographic matching, and country-level collaboration networks. The findings reveal that the vast majority of current research is concentrated in engineering and technology-focused fields, and that digital twins and artificial intelligence are emerging themes in this area. Educational theories, pedagogical models, and learning-centered frameworks remain limited in the literature. While China and Italy emerge as leading countries in publication output, international collaboration networks are still in their developmental stages. The study highlights the need for education-focused, theory-based research and practical applications. A significant limitation is the use of data from a single database, Scopus. Future studies are recommended to include other databases.*

Keywords: Artificial intelligence, Education, Digital Twins, Technology, AI Enhanced Learning.

1. Introduction

Industry 4.0 and 5.0 societies represent social dynamics dominated by technology. These societies utilize technological tools created by technological advancements in various sectors of society. This technology, called information technology, has led to the evolution of systems into a digital form. Developments in artificial intelligence, cloud computing and the Internet of Things have triggered the use of digital data and accelerated the digital transformation process (Schroeder et al., 2016; Qi and Tao, 2018; Ga et al., 2025) and have become institutionalized (Hazrat et al., 2023). Digital Twin technology is also a result of this evolution and contributes to the digitalization of systems.

The Digital Twin phenomenon refers to the effort to design, test, produce, and use a virtual version of a system, and was first used in a presentation at the University of Michigan in 2003 (Grivers, 2014; Grieves & Vickers, 2017).

Rosen et al. (2015) The concept of a digital twin can be defined as autonomous structures based on highly realistic virtual representations of systems interacting with the physical world and their operational dynamics. When the definitions are examined, it is understood that Digital Twin technology is considered a technological tool that helps predict design, operation and future state of the system. For example, a Digital Twin model developed by Korkmaz et al. (2025).

A Digital Twin system integrates an existing physical system with created virtual counterpart that represents and mirrors all information related to the physical system (Grivers & Vickers, 2017). This technology has been adopted in engineering, aviation, architecture, telecommunications, automotive, healthcare, and urban planning etc. (Madubuike et al., 2022; Lauria & Azzalin, 2024; Omran et al., 2024; Palabiyik & Demircan, 2025; Stufano Melone et al., 2025). The literature shows that the Covid-19 pandemic accelerated the adoption of Digital Twin technologies (Hazrat et al., 2023; Stufano Melone et al., 2025). Digital Twins offer an innovative tool for interactive learning in educational science. With this enabling students to explore and interact with real-world applications in a virtual environment (Tao et al., 2018). Through Digital Twin technology-supported learning, students will achieve very different outcomes compared to traditional education, using a connection between physical and virtual systems. Digital technology has triggered the formation of a new education system. To meet the technological demands of the era, education systems must revise their teaching processes and learning content to adapt to new technologies.

In Palabiyik and Demircan's (2025) study, it was emphasized that the integration of Digital Twin technology into educational programs will encourage simulation-focused product development methodologies and applied learning approaches, improve interdisciplinary collaboration and enhance students' decision-making and problem-solving skills.

In Ljaniemi and Paavilainen's (2020) study, it was determined that digital tools and digital technology can increase students' responsibility in learning. The literature shows that theoretical knowledge regarding Digital Twin technologies, particularly in educational science and in general, has not reached its saturation point. Furthermore, the existence of problems in the application of Digital Twin technology is noteworthy. As Ba et al. (2025) also emphasize, despite the potential of Digital Twin technology, there are applications, benefits, and challenges. Among the challenges are high implementation costs, data security risks. Arsecularatne et al. (2024) also highlight in their study that the obstacles to using Digital Twin technology include interoperability issues, privacy and data quality challenges. The aim of this research is to find research trends related to AI-powered digital twins in education, identify research trends, and guide researchers who will conduct scientific studies in this field. To achieve the research objective, the following questions were addressed:

1. What is the author citation distribution related to AI-Enhanced Digital Twins for Education?

2. What is the keyword co-occurrence structure of the studies in the field?
3. How is bibliographic coupling formed between documents?
4. What is the bibliographic coupling structure between journals?
5. What are the bibliographic coupling and collaboration networks at the country level?

2. Method

This study, conducted to explore research trends on AI-enhanced digital twins in education, utilized a bibliometric analysis method. The distribution of documents published in the Scopus database by year, the most productive countries in the field, citations, and the most frequently used keywords in the documents were analyzed. The keywords TITLE-ABS-KEY (artificial, intelligence, enhanced, digital, and twins) were used in the data collection process, which concluded on November 19, 2025. Using VosViewer software, this study examined “Author citations, Simultaneity of all keywords, Bibliographic matching of documents, Bibliographic matching of sources, and Bibliographic matching of countries.” The analysis of 494 studies on “AI-Enhanced Digital Twins for Education” was presented in tabular form and graphs.

3. Results

3.1 Citation of authors

In the citation analysis of the authors, the minimum number of documents per author was set at 1, while the minimum number of citations per author was set at 10. For the ten authors meeting these criteria, the total strength of their citation links with other researchers was calculated. The authors with the highest number of citations are presented in Figure 1 and Table 1.

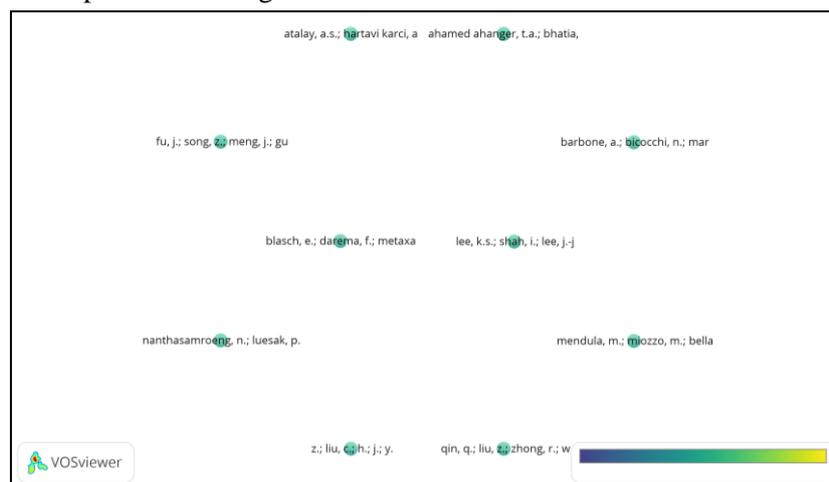


Figure 1. Citation of authors

Table 1. Citation of Authors

Id	Author	Documents	Citations	Total link strength (TLS)
1	ahamed ahanger, t.a.; bhatia, m.; alabduljabbar, a.; albanyan, a.	1	0	0
2	atalay, a.s.; hartavi karci, a.e.h.; arif, i.; ergün, s.; kanak, a.	1	0	0
3	barbone, a.; bicocchi, n.; martinelli, m.; morandi, r.; picone, m.	1	0	0
4	blasch, e.; darema, f.; metaxas, d.	1	0	0
5	fu, j.; song, z.; meng, j.; guo, j.; yang, k.; liu, w.; l.	1	0	0
6	lee, k.s.; shah, i.; lee, j.-j.; ghahramani, a.	1	0	0
7	mendula, m.; miozzo, m.; bellavista, p.; dini, p.	1	0	0
8	nanthasamroeng, n.; luesak, p.; pitakaso, r.; khonjun, s.; jirasirilerd, g.; matitopanum, s.	1	0	0
9	qin, q.; liu, z.; zhong, r.; wang, x.v.; wang, l.; wiktorsson, m.; wang, w.	1	2	0
10	z.; liu, c.; h.; j.; y.	1	0	0

The most cited authors are “qin, q.; liu, z.; zhong, r.; wang, x.v.; wang, l.; wiktorsson, m.; wang, w. ak”.

3.2 Co-occurrence-all keywords

In this study, performing the relevant analysis for ai-enhanced digital twins for education, the “minimum number of occurrences of a keyword” was identified as 2. Among the 171 keywords, 14 meet the thresholds”. In Figure 2 and Table 2 highlights the ”co-occurrence-all keywords”.

Table 2. Table for co-occurrence-all keywords

Id	Keyword	Occurrences	Total link strength (TLS)
10	artificial intelligence	5	18
16	behavioral research	2	12
30	cybe-physical systems	2	13
31	cyber physical system	2	13
32	cyber-physical systems	2	13
38	decision making	3	17

Id	Keyword	Occurrences	Total link strength (TLS)
39	deep learning	3	7
42	digital twin	5	20
52	dynamics	2	6
60	embedded systems	2	13
68	environmental technology	2	10
105	internet of things	4	16
120	manufacturing industries	2	8
158	smart manufacturing	2	8

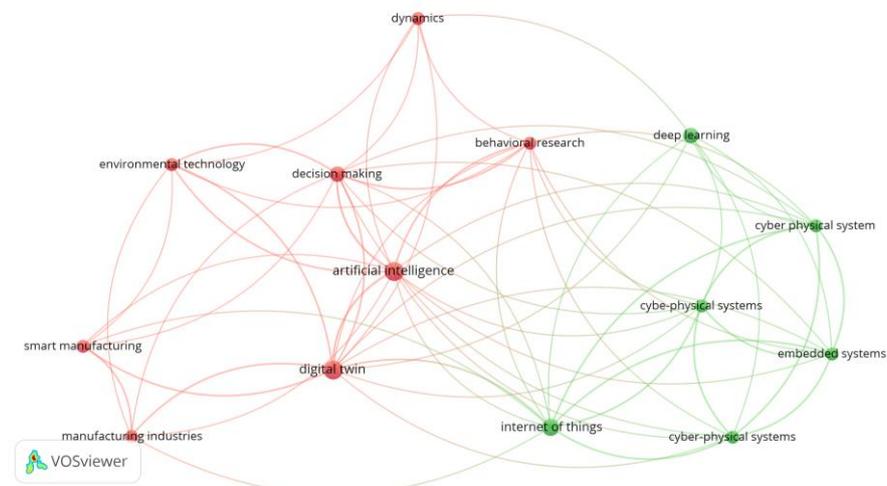


Figure 2. Graph generated with vosviewer for co-occurrence-all keywords

An examination of the co-occurrence-all keyword results clearly shows that research in the field of AI-Enhanced Digital Twins for Education is distributed into distinct thematic clusters. The findings indicate that there are studies focusing on both conceptual and application-oriented aspects of the field. According to the analysis results, the keywords “digital twin” (occurrences = 5, total link strength = 20) and “artificial intelligence” (occurrences = 5, total link strength = 18) are the most prominent keywords. This reveals that digital twins are increasingly being integrated with artificial intelligence-based methods, and the literature is structured around these two concepts. The high correlation strength of the keywords “decision making” (occurrences = 3, tls = 17) and “internet of things” (occurrences = 4, tls = 16) reveals that AI-powered digital twins are considered to be strongly related to decision-making processes and IoT-based data ecosystems. Furthermore, the keywords “cyber-physical systems” (tls = 13), “embedded systems” (tls = 13), and “deep learning” (tls = 7) clearly show that computational and system-level approaches, which form the technical infrastructure of digital twins, also hold a

significant place in the literature. When evaluated in terms of application areas, the keywords “manufacturing industries” and “smart manufacturing” (tls = 8) also show that the majority of studies are focused on Industry 4.0. When all the findings are examined, it shows that the field in question is a rapidly growing research area with both theoretical and practical diversity.

3.3 Bibliographic coupling of documents

In this study, conducting the relevant analysis for ai-enhanced digital twins for education, the “minimum number of citations of a document” was selected as 0 of the 10 documents, 10 meet the threshold. In figure 3 and table 3 shows that “bibliographic coupling of documents”.

Table 3. Bibliographic coupling of documents

ID	Document	Citations	Total Link Strength (TLS)
1	Mendula (2026)	0	1
2	Fu (2026)	0	0
3	Qin (2026)	2	0
4	Barbone (2026)	0	1
5	Lee (2026)	0	0
6	Ahamed Ahanger (2026)	0	0
7	Z.; Liu (2026)	0	0
8	Nanthasamroeng (2026)	0	0
9	Atalay (2026)	0	0
10	Blasch (2026)	0	0

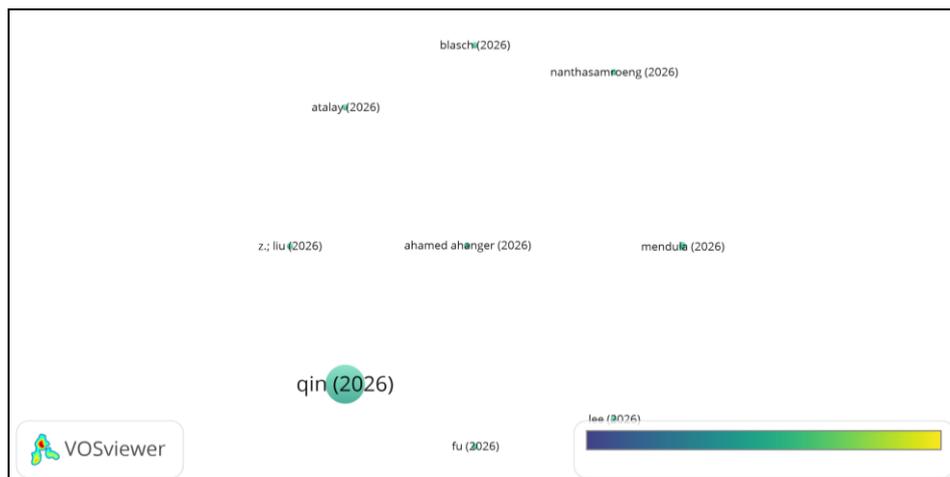


Figure 3. Graph generated with VosViewer for bibliographic coupling of documents

As shown in Table 3, the vast majority of publications related to AI-Enhanced Digital Twins for Education have not yet received citations. Among the documents examined, only Qin's (2026) study was found to have received citations ($n = 2$).

3.4 Bibliographic coupling of sources

For a source to be considered for analysis, a minimum of 1 document and 0 citations were required. According to these criteria, all 7 sources analyzed ($n = 7$) met the specified requirements.

Table 4. Bibliographic coupling of sources

ID	Source	Documents	Citations	Total Link Strength (TLS)
1	Building and Environment	1	0	0
2	Engineering Applications of AI	3	0	0
3	Future Generation Computer Systems	2	0	0
4	Journal of Energy Chemistry	1	0	0
5	Lecture Notes in Computer Science	1	0	0
6	Lecture Notes in Mobility	1	0	0
7	Robotics and Computer-Integrated Manufacturing	1	2	0

As shown in Table 4, the bibliographic coupling of sources analysis reveals that the studies on Enhanced Digital Twins for Education are predominantly published in engineering and artificial intelligence-focused journals such as Engineering Applications of Artificial Intelligence and Future Generation Computer Systems, indicating that the topic is addressed more in technology-focused journals than in education-focused journals. These findings highlight the need for studies in the field of education.

3.5 Bibliographic coupling of countries

For a source to be considered for analysis, a minimum of 1 document and 0 citations were required. According to these criteria, all 7 sources analyzed ($n = 7$) met the specified requirements.

Table 5. Bibliographic coupling of countries

4	Country	Documents	Citations	Total Link Strength (TLS)
1	China	3	2	19
2	Denmark	1	0	9
3	Estonia	1	0	30

4 Country	Documents	Citations	Total Link Strength (TLS)
4 India	1	0	10
5 Italy	2	0	11
6 Poland	1	0	30
7 Saudi Arabia	1	0	10
8 Singapore	1	0	0
9 Spain	1	0	11
10 Sweden	1	2	10
11 Thailand	1	0	0
12 Turkey	1	0	30
13 United Kingdom	1	0	30
14 United States	1	0	0

According to the country-level analysis, when looking at the number of documents in the field of AI-Enhanced Digital Twins for Education, China (n = 3) and Italy (n = 2) stand out. When examining the citation distribution, it was determined that studies from China and Sweden received the most citations. In contrast, countries such as Estonia, Poland, Turkey, and the United Kingdom showed a high total link strength (TLS = 30).

4. Discussions and conclusions

Research on AI-powered digital twins in education appears to be in its early stages. Studies are largely technology-focused. The limited integration of learning theories and pedagogical models therefore restricts this educational approach. Future research should incorporate theory-based, student-centered approaches and applications of digital twins in education to strengthen the interdisciplinary and educational impact of this field. This study examines research trends in the field of "Exploring Research Trends on AI-Enhanced Digital Twins for Education" through bibliometric analysis, revealing the current state of the field and potential future research trends. The findings indicate that the limited number of publications and citations in this area suggests it is a new and emerging research field. Keyword analysis reveals that many studies revolve around digital twins and artificial intelligence, with a particular emphasis on technology-focused themes such as decision-making, the Internet of Things, and cyber-physical systems. Bibliographic coupling of sources shows that most studies are published in engineering and AI-focused journals, with the educational aspect remaining secondary. This suggests that there may be innovations in this field in terms of educational applications, and that research in this area could gain prominence. At the country level, China and Italy stand out in terms of publication numbers. The increasing collaboration networks between different countries indicate that collaborative research could contribute to the field of education. In conclusion, AI-enhanced digital twins offer

significant opportunities for the field of education. It is believed that future studies focusing on education will bring innovation to the field and set trends. In this study in significant limitation is the use of data from a single database, Scopus. Future studies are recommended to include other databases.

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