Croatian Journal of Education
Vol.28; No.2/2026, pages: 699-732
Review paper
Paper submitted: 1st February 2025
Paper accepted: 26th January 2026
https://doi.org/10.15516/cje.v28i2.42887

Emerging Trends and Patterns in the Use of Wearable Technology (WT) in Schools (1999-2024): A Scientometric Perspective

Hongshuai Shi[1] and Amir Karimi[2]
[1]School of Education, Jiangxi Normal University
Department of Port Machinery and Chemical Engineering, Zhoushan Technician College
[2]Department of History, Faculty of Law and Social Sciences, University of Tabriz

Abstract

This article examines the trends in wearable technology (WT) in education from 1999 to 2024, using a scientometric approach to analyze research evolution. A total of 248 original articles were extracted from 165 distinct journals. These articles were subsequently analyzed utilizing three specialized software tools: CiteSpace, VOSviewer, and the R programming package. Over the past two decades, the number of scholarly articles has increased by about 9 %. However, in recent years, attention and review success have declined. The US and China are leading WT research, supported by substantial funding and engineering programs, with US universities at the forefront. Countries like India, Japan, Finland, Bahrain, and Turkey contribute significantly, indicating global interest in this field. Key studies emphasize emotional learning benefits for students with autism and the integration of machine learning in WT, promoting interactive STEM education. Findings highlight a shift towards student-centered approaches and specialized applications, such as medical devices. The article underscores the evolving landscape of wearable technology in schools and the need for ongoing research and collaboration to enhance educational outcomes and create inclusive learning environments.

Keywords: *educational technology; scientometric; technology integration; trend analysis; wearable technology.*

Introduction

Wearable technology (WT) and wearable devices (WDs) have quickly evolved into essential tools that improve many facets of everyday life (Chong et al., 2020) by providing useful features that go beyond those of traditional computer and communication devices (Ferreira et al., 2021; Motti, 2020a). Their relevance as essential and valuable tools in the present day is further demonstrated by their ability to completely transform how we communicate, learn, stay healthy, and travel.

A collection of electronic gadgets known as WT is incorporated into apparel or accessories or worn on the body (Meena et al., 2023). These gadgets offer customers comfortable hands-free access to information, communication, and functionality thanks to their cutting-edge sensors and technology (Egeli & Kurgun, 2021). Fitness monitoring (Greiwe & Nyenhuis, 2020), communication (Ferreira et al., 2021), virtual reality (VR) and augmented reality (AR) (Kim et al., 2021), personal safety, productivity (Patel et al., 2022), healthcare (Mejia et al., 2021), and fashion (Versteeg et al., 2020) are among the popular uses. Real-time management of health objectives is enabled by fitness bands, smartwatches, and bright clothes (Sucharitha et al., 2022), which track heart rate, calories burned, sleep patterns, and physical activity. While VR and AR headsets enable immersive experiences (De Canio et al., 2022), smartwatches and eyewear allow users to access information hands-free (Motti, 2020b). So, WT will continue to find additional uses in a broader range of industries as it develops.

Because of offering creative methods to improve teaching and learning (Almusawi et al., 2021a; Havard & Podsiad, 2020), WT has the potential to completely transform the educational system (Almusawi et al., 2021a). It collects student data (Vijayan et al., 2021), delivers tailored feedback, and creates engaging virtual worlds (Yin et al., 2021). Additionally, WT supports students with impairments, facilitates collaborative learning (Zeagler et al., 2021), translates languages in real-time, and collects accurate data on individual pupils (Al-Emran et al., 2023). They also give immediate feedback on teaching strategies and classroom management to teachers enrolled in teacher preparation programs (Mill et al., 2021). Although WT in education has not yet reached its full potential, these examples demonstrate the importance of having individualized, dynamic, and engaging learning environments for both teachers and students.

Therefore, hands-on, experiential learning is also possible through WDs, allowing students to engage directly with educational content (Montesinos et al., 2022). Moreover, this approach encourages active exploration, critical thinking, and a deeper understanding of complex concepts (AlGerafi et al., 2023), also supports special education and diverse learning needs (Cheng & Lai, 2020), providing accommodations for students with diverse learning styles and abilities (Conderman et al., 2021). To build trust in WT in educational settings, schools must establish strong policies and procedures to protect student data and privacy, while adhering to laws such as FERPA and COPPA (Cahyanto et al., 2023). Precise data collection, storage, and usage guidelines are also critical, and open communication with parents, educators, and students is essential. By recognizing the importance and innovation of WT in education, the need to examine the number of articles published in this field becomes evident, which forces researchers to conduct scientometric research. Still, new research fields, research conversations, and existing trends in this field have not been thoroughly studied, despite numerous review articles.

In addition to mapping the body of existing knowledge (Kastrin & Hristovski, 2021) and identifying significant contributors, trends (Rawat & Sood, 2021), and emerging areas of focus (Goerlandt & Li, 2022), scientometric research is essential for understanding the research landscape, identifying research gaps (Sheikhnejad & Yigitcanlar, 2020), influencing policy decisions, fostering collaboration (Mashur et al., 2023), and assessing the impact of research (Sedighi, 2020). It also helps set research priorities and create policies to integrate WT into the classroom (Kajikawa, 2022). The sector is constantly changing, and scientometric analysis helps monitor trends in WT in education and serves as a standard for analyzing production, impact, and research influence. For this reason, scientometric research is crucial to advancing WT in education.

Literature review

According to Chu et al. (2023), despite advancements in WT, it has yet to be integrated into the educational curriculum. The majority of evaluations focus on the basic features of wearables (Kumari et al., 2017) rather than niche markets such as healthcare (Baig et al., 2013), assistive technology, or security (Blasco et al., 2016). Several surveys and review articles on wearables for learning were identified through a literature search (Borthwick et al., 2015; De Freitas & Levene, 2003; Labus et al., 2015). These comprise a wearables report, a Google Glass study by Sapargaliyev (2015), and a survey by Attallah & Ilagure (2018) that addresses cost, usability, distraction, technological anxiety, and the requirement that wearables be connected to smartphones. Lee & Shapiro's (2019) essay examines current WT initiatives and highlights their educational potential. It examines several assistance methods, such as digital integration, role-play, notifications, bodily experience recordings, and personal expression. The best devices identified in a meta-analysis of Harvard and Podsiad's (2020) research were smartwatches, fitness trackers, and head-mounted displays. The methods, theories, types, applications, and research foci of WT in education are examined in the literature review by Almusawi and colleagues (2021). It discusses future avenues for study and the theoretical underpinnings. In the end, Chu and colleagues (2023) offer a framework of five essential components, list seven ways wearables might support learning, and identify unexplored research areas based on their review.

In addition, as a scientometric study, Cheng and Yao (2019) share similarities with the referenced articles in their focus on evaluating the impact and trends within the Use of WT for English Learning. The study uses Citespace to examine research trends in WDs. Virtual reality (VR) classrooms and the incorporation of mobile learning are two developments identified in English teaching. According to the survey, WDs will have more educational opportunities in the future.

The publications on WT in education include some flaws, including poor sample techniques, a vague temporal scope, and a lack of precision in the procedures (Almusawi et al., 2021b; de-la-Fuente-Robles et al., 2022; Kageyama et al., 2022; Ram, 2024; Tırpan & Semiz, 2022; Yilik, 2023). These problems may limit the practical significance of the research by casting doubt on the validity and reliability of its results. To improve the validity, relevance, and applicability of these findings, this research strongly emphasizes honest reporting of sampling procedures, clear presentation of methodology, and definition of the temporal scope. Then, this article aims to examine the scientometrics of the articles released in WT by addressing the subsequent research inquiries:

What patterns can be identified in the overall trend of article publications and citation frequencies within the field?

RQ1. How do publication trends vary across different countries and institutions, and what implications do these trends have for global research collaboration?

RQ2. What types of references are predominantly utilized within the article system, and how do they contribute to the development of the field?

RQ3. What significant changes have occurred in the field trends and the subject map in recent years, and how do these changes reflect the evolving research landscape?

Methodology

Search strategy and data collection

The present study employed data sourced from the Web of Science (WoS) database, with extraction conducted on January 10, 2025, to systematically address the defined research questions. WoS was selected over alternative databases, such as Scopus, primarily because of its broader, more comprehensive coverage of pertinent literature within the scope of history textbook research, thereby ensuring a richer, more representative dataset. This choice aligns with the intention to construct a detailed, interdisciplinary citation profile, thereby facilitating a nuanced understanding of scholarly communication patterns. Data organization was managed using Microsoft Excel, while advanced bibliometric visualization and network analysis tools—including CiteSpace, VOSviewer, and Bibliometrix—were employed to generate sophisticated network diagrams, consistent with methodologies adopted in prior bibliometric investigations. The reliance on these contemporary analytical tools reflects a recognition that traditional descriptive bibliometric approaches have proven inadequate in addressing the complex and evolving challenges inherent in this research domain (Li & Karimi, 2025). To ensure methodological rigor, explicit inclusion criteria were established. The data extraction process from the Scopus database utilized a specific search strategy that incorporated the following keywords: ”Wearable tech*” OR ”Wearable device*” OR ”Wearable electron*” OR ”Wearable sensor*” OR ”Wearable comput*” AND ”educat*” OR ”teach*” OR ”instruct*” OR ”learn*” OR ”train*” AND school*”

AND NOT Excluding ”animal*” OR ”patient*” OR ”adult*” OR ”medical school*” OR ”medical education*” (Fig 1).

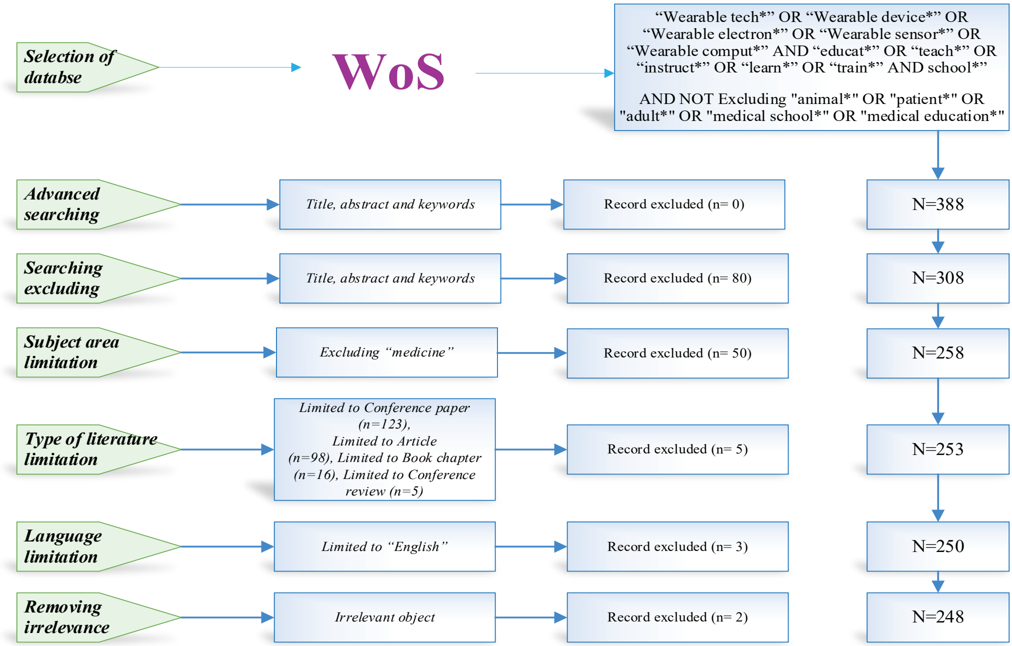


Figure 1. The methodological data collection and analysis strategy

The data collection process followed a systematic, multi-stage filtering strategy, as illustrated in Fig. 1, beginning with selecting the Scopus database as the primary source due to its comprehensive indexing of peer-reviewed international research. An advanced search query combining wearable technology and education-related terms was applied to the Title, Abstract, and Keywords fields, yielding an initial set of 388 records. A subsequent refinement step involved excluding publications containing terms associated with non-educational or clinical contexts, such as animal, patient, or medical school–related studies; this reduced the dataset to 308 records. To further ensure conceptual alignment with the study’s focus, a subject-area filter was applied to remove research categorized under medical fields, eliminating an additional 50 articles and bringing the total to 258. The next stage involved restricting the dataset to accepted academic publication formats—conference papers, journal articles, book chapters, and conference reviews—removing five records and resulting in a revised total of 253. A language filter was then applied, limiting the corpus to English-language publications to ensure analytical consistency, resulting in the exclusion of three additional texts. Finally, a manual relevance screening was conducted to remove records that, despite meeting technical search criteria, did not substantively relate to wearable technologies in educational settings, thereby removing two further items and producing a final dataset of 248 publications and extracted in CSV, RIs, Plain

Text, and BibTeX file formats (Shen et al., 2025). This systematic data extraction and selection process underscores the study's commitment to methodological precision and to generating robust, generalizable insights into the evolving landscape of the educational aspect of WT research.

Bibliographic mapping software

The discipline of scientometrics uses a variety of essential software applications to analyze and visualize data. Notable tools include Microsoft Excel (2013), CiteSpace (6.3.1), VOSviewer (1.6.20), and the Bibliometrix package (3.1.4), which functions within the R programming environment (3.6.3). These software programs are vital in bibliometrics, each providing unique functionalities that address various analytical requirements (Fig. 2). Together, the combined use of Excel, CiteSpace, VOSviewer, and Bibliometrix enabled a comprehensive identification of publication patterns, intellectual structures, and thematic trends within the dataset.

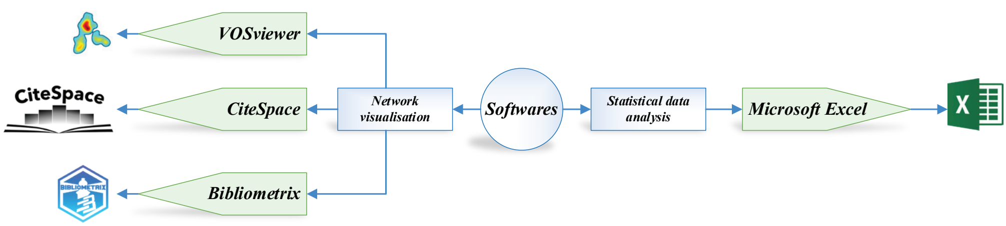


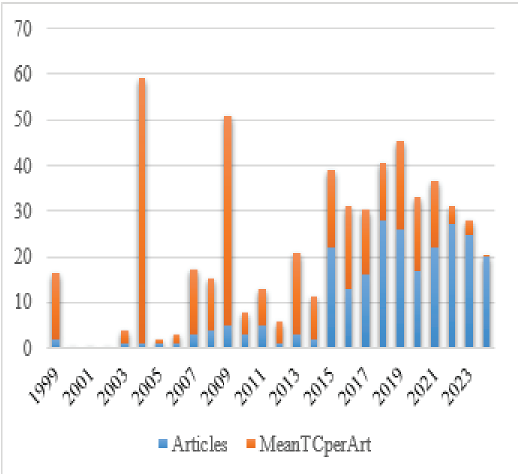
Figure 2. Data visualization software

Results

Primary information

Table 1
Primary information about the collected documents

Description	Results
Time range	1999-2024
Sources (journals, books, etc.)	165
Documents	248
Annual growth rate %	9,65
Average document age	6,71
Average number of citations per document	12,17
Keywords plus (ID)	1757
Author keywords (DE)	785
Authors	867
Authors of documents with one author	29
Documents with one author	44
Co-authors per document	3,88
International co-authorship %	16,13



Description	Results
Timespan	1999:2024
Sources (Journals, Books, etc)	165
Documents	248
Annual Growth Rate %	9.65
Document Average Age	6.71
Average citations per doc	12.17
Keywords Plus (ID)	1757
Author's Keywords (DE)	785
Authors	867
Authors of single-authored docs	29
Single-authored docs	44
Co-Authors per Doc	3.88
International co-authorships %	16.13

Figure 3. Annual Production and Citation

Fig. 3 illustrates a fluctuating trend in the number of articles published and the mean total citations per article (MeanTCperArt). Initially, in 1999, there were two articles with a mean citation of 14.5, but the following years saw a significant drop, with no articles published from 2000 to 2002. A slight recovery occurred in 2003 with 1 article, but it was not until 2005 that the output stabilized, albeit with low citation counts. From 2007 to 2014, there was a gradual increase in articles and citations, peaking in 2015 with 22 articles and a mean citation of 16.86. However, after this peak, the number of articles published remained relatively high but with a noticeable decline in citation impact, particularly in 2022 and 2023, where the mean citations dropped to 4.3 and 2.84, respectively. 2024 shows a further decrease in citation impact, with a mean of only 0.4 citations per article. While publication volume increased over the years, citation impact appears to have diminished significantly in later years, suggesting a potential need for improved research quality or relevance in the current academic landscape.

Table 1 shows robust academic output, with 248 documents sourced from 165 journals and books. The annual growth rate of 9.65 % indicates a healthy increase in research activity over the years. On average, documents are 6.71 years old, suggesting a mix of recent and established research. Each document averages 12.17 citations, reflecting its impact within the academic community. The presence of 1,757 Keywords Plus and 785 authors' keywords highlights a diverse range of topics. With 867 authors contributing to the body of work, including 29 single-authors, collaboration is evident, as indicated by an average of 3.88 co-authors per document and a 16.13 % rate of international co-authorships.

Leader countries, affiliations, and articles

Table 2 (part A) illustrates a diverse range of affiliations, with the University of Ljubljana leading with eight documents, indicating a strong presence in this area.

Table 2
The ten most influential countries and affiliations of WT in schools

(A)		(B)		(C)		
Affiliation	Docs	Region	Docs	Region	TC	Average Article Citations
University of Ljubljana (Slovenia) ▲	8	USA (North America)	147	USA	667	20.80
Stanford University (United States) ▲	6	China (Asia) ▲	74	China	243	9.30
University of British Columbia (Canada) ▲	6	India (Asia) ▲	22	Spain	120	17.10
The University of Texas at Austin (United States)	5	Japan (Asia)	21	Finland ★	106	35.30
University of California (United States)	5	Italy (Europe) ▼	20	Korea	95	23.80
University of Maryland (United States)	5	Spain (Europe)	20	Hong Kong	65	21.70
University of Pennsylvania (United States) ▼	5	UK (Europe)	17	Bahrain ★	64	64.00
Utah State University (United States) ▼	5	Canada (North America)	15	Turkey ★	62	31.00
East China Normal University (China)	4	Germany (Europe)	13	United Kingdom	61	12.20
Aarhus University (Denmark)	3	Australia (Australia)	12	Cyprus	56	18.70

The following are several prominent institutions from the United States, including Stanford University, the University of Texas at Austin, and the University of California, each contributing 5 to 6 documents. Notably, the University of British Columbia and the University of Maryland also have solid representations, with 6 and 5 papers, respectively. Internationally, East China Normal University and Aarhus University add to the mix, highlighting a global interest in WT research. Overall, the information suggests a robust engagement from North American and European institutions, with Slovenia's University of Ljubljana as a key contributor. Parts B & C provided a comparative analysis of academic output and citation impact related to WT in schools across different regions. The USA leads with 147 documents and 667 citations, for an average of 20.80 citations per article, indicating a strong academic presence. China follows with 74 documents and 243 citations, yielding a lower average of 9.30 citations per article, suggesting less impact per output. Japan, with 21 documents, has a high average citation rate of 35.30, indicating that its articles are frequently cited despite a smaller output. In Europe, Spain and Italy each have 20 documents, but Spain's average citation of 17.10 is lower than Italy's 23.80, suggesting Italy's work has a greater impact. The UK, with only 17 documents, stands out with an impressive average of 64.00 citations, highlighting its influential contributions. Canada and Germany show lower outputs and citation averages, while Australia has the fewest documents (12) but maintains a respectable average of 18.70. Overall, the data illustrate varying levels of academic productivity and citation impact, with the USA and the UK identified as significant contributors.

Leader references

Table 3

The ten most influential articles of WT in school

Paper	Source	TC	TC per Year	Normalized TC
(Picard, 2009)	*"Philosophical Transactions of the Royal Society B: Biological Sciences"*	162	9.53	3.54
(Zimmermann-Niefield et al., 2019)	*"Proceedings of the 18th ACM International Conference on Interaction Design and Children"*	118	16.86	6.15
(Kireev et al., 2021)	*"Nature Protocols"*	84	16.80	5.70
(Lindberg et al., 2016)	*"IEEE transactions on learning technologies"*	78	7.80	4.26
(D. A. Fields et al., 2018)	*"Equity & Excellence in Education"*	71	8.88	5.70
(Haataja et al., 2018)	*"Computers in Human Behavior"*	70	8.75	5.62
(Almusawi et al., 2021a)	*"Computers & Education"*	64	12.80	4.35
(Gao et al., 2020)	*"Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous …"*	63	10.50	3.92
(Can et al., 2020)	*"IEEE Access"*	59	9.83	3.67
(Klopfer et al., 2004)	*"Journal of Computer Assisted Learning"*	58	2.64	1.00

Table 3 shows a diverse range of contributions that highlight the impact of technology on learning and teaching. Picard (2009) stands out with the highest total citations (TC) of 162, focusing on effective technologies to support students with autism, with significant implications for emotional learning. Zimmermann-Niefield and colleagues (2019) follow closely with 118 citations and a remarkable TC per year of 16.86, indicating a rapid rise in relevance due to their exploration of machine learning applications in education. Kireev and colleagues (2021) also report a high TC per year (16.80) in their work on graphene electronic tattoos, suggesting innovative health-monitoring applications in schools. Other notable articles include Lindberg and colleagues (2016) and Fields and colleagues (2018), which emphasize the importance of physical education and equity in computer science, respectively, while maintaining solid normalized citation rates. Almusawi and colleagues (2021) and Gao and colleagues (2020) contribute to the discourse on teacher readiness and student engagement, reflecting current educational priorities. Overall, these articles underscore WT's transformative potential to enhance educational experiences, promote inclusivity, and address mental health, while also indicating a growing interest in the field, as evidenced by rising citation rates in recent years.

The integration of WT in educational settings has been explored through various studies, each highlighting its transformative potential. Picard (2009) explores affective technology for autism, indicating that wearables can support emotional communication for students with autism. Zimmermann-Niefield and colleagues (2019) emphasize the role of wearables in teaching machine learning through practical applications, making STEM education more engaging. Kireev and colleagues (2021) investigate graphene electronic tattoos and suggest innovative applications for health monitoring in educational contexts. Lindberg and colleagues (2016) discuss enhancing physical education through exergames and WT, which can increase student engagement in physical activity. Fields and colleagues (2018) discuss the use of electronic textiles in high school computer science to promote equity, demonstrating how hands-on learning can engage diverse learners. Haataja and colleagues (2018) explore the relationship between observed behaviors and physiological synchrony in collaborative learning, indicating that WT can improve group interactions. Klopfer and colleagues (2004) highlight the effectiveness of WDs in participatory simulations, promoting active learning experiences. Almusawi and colleagues (2021) examine teachers' readiness to incorporate WT into physical education, revealing that while educators see its benefits, concerns about training and resources persist, underscoring the need for professional development. Gao and colleagues (2020) present a system for predicting emotional and cognitive engagement in classrooms, which can help tailor teaching strategies to enhance student involvement. Lastly, Can and colleagues (2020) focus on smartwatches for monitoring personal stress levels, suggesting that such technology can help educators proactively address student well-being and mental health.

Trend and cluster analysis

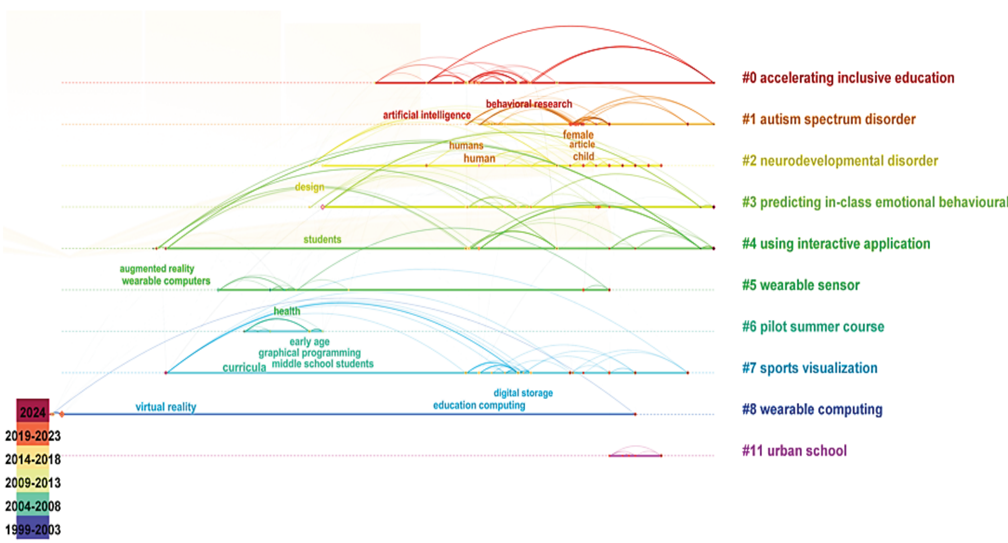


Figure 4. Keyword co-occurrence analysis of WT in the schools

Fig. 4 demonstrates a diverse grouping of members, with the largest cluster (#0) comprising 40 members and a silhouette value of 0.782, indicating moderate cohesion. The second largest cluster (#1) also has 40 members but boasts a higher silhouette value of 0.939, suggesting it is more distinct and well-defined. The subsequent clusters vary in size and silhouette values, with the fifth cluster (#4) showing a high silhouette value of 0.968, indicating a strong separation from the other clusters. Notably, the smallest cluster (#11) has only five members but achieves an impressive silhouette value of 0.994, highlighting its clear distinction.

Table 4
Summary of the most significant 10 clusters of WT in the school

ClusterID	Size	Silhouette	Label (LSI)	Label (LLR)	Average Year	The Major Citing Article
#0	40	0.782	Education policies	Accelerating inclusive education	2016	(Lenz et al., 2016)
#1	40	0.939	Autism spectrum disorder	Autism spectrum disorder	2019	(Muñoz-Organero et al., 2019)
#2	27	0.827	Neurodevelopmental disorder	Neurodevelop-mental disorder	2018	(Garzotto et al., 2018)
#3	27	0.779	Computer science	Predicting in-class emotional behavioral	2018	(D. Fields et al., 2017)
#4	25	0.968	WT	Using an interactive application	2015	(Vishkaie, 2018)
#5	21	0.957	Wearable sensor	Wearable sensor	2009	(McIlwraith et al., 2008)
#6	21	0.983	Learning programming	Pilot summer course	2008	(Lau et al., 2009)
#7	20	0.934	Wearable device	Sports visualization	2017	(Wang, 2017)
#8	12	0.951	WT	Wearable sensor	2000	(Panayi et al., 1999)
#11	5	0.994	Teaching biology	Urban school	2021	(Kaul & Pooja, 2021)

Table 4 displays citation counts across various clusters highlights the prominence of WT, which stands out in Cluster #8 with an impressive 90 citations, indicating its significant impact in the field. Cluster #3, which focuses on students, accumulates 60 citations, underscoring the importance of student-centered research in educational contexts. Cluster #4, featuring wearable computers, also shows strong relevance with 48 citations, while wearable sensors in Cluster #5 and teaching in Cluster #8 share the fourth position with 31 citations each. Other notable topics include WDs and engineering education, with an emphasis on technology integration in learning environments. The presence of diverse themes such as physical activity, e-learning, and education computing across the clusters suggests a rich interplay between technology and education, reflecting current trends and interests in enhancing learning experiences.

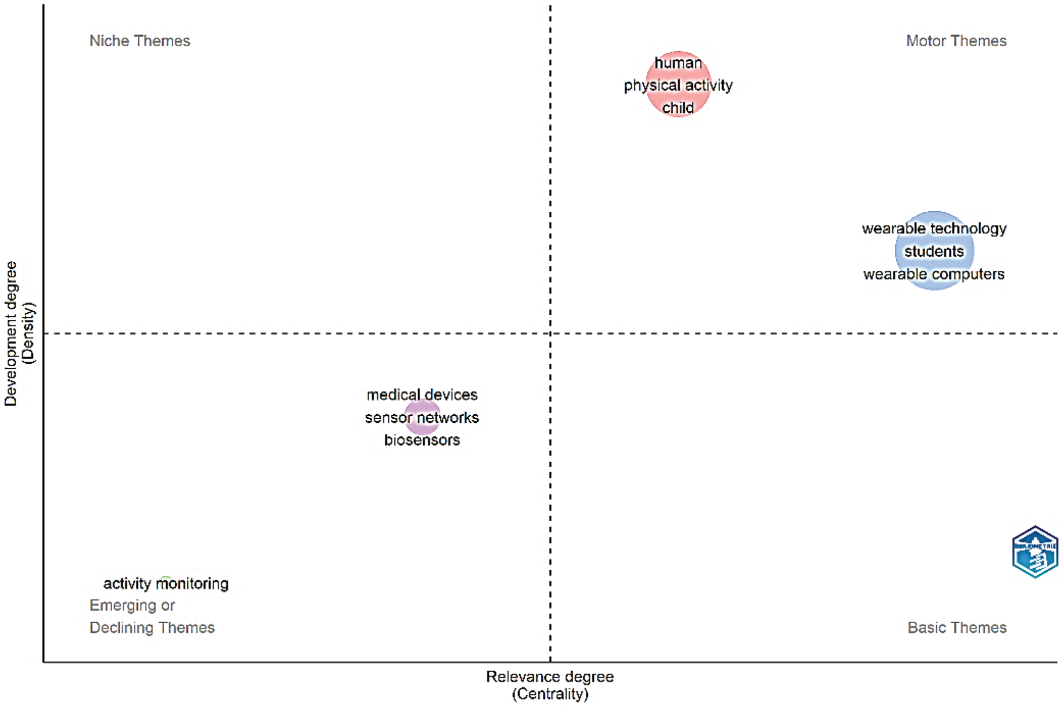


Figure 5. Thematic map of WT in the School system

The thematic system of WT in schools reveals a rich interplay between established motor themes and emerging trends (Fig. 5). Clusters 1 and 2 highlight the foundational aspects of WT, focusing on human interaction, physical activity, and the integration of WDs in educational settings. Key terms such as "students," "wearable sensors," and "teaching" underscore the emphasis on enhancing learning experiences through technology. In contrast, clusters 3 and 4 reflect a shift towards more specialized and innovative applications, such as "medical devices," "sensor networks," and "biosensors," indicating a growing interest in health monitoring and data-driven insights within educational contexts. This thematic evolution suggests that while traditional educational practices remain vital, there is a significant shift towards leveraging advanced technologies to foster engagement, support diverse learning needs, and promote students' overall well-being.

The coverage analysis (Fig. 6) shows that keywords can be categorized into two distinct groups. The first category, represented by a light oil blue color, encompasses foundational and supportive concepts that have established significance in the field. This cluster includes terms such as wearable computing (2016 Apy), wearable sensors (2017 Avr.pub.year), WT (2018 Apy), sensors (2014 Apy), and ubiquitous computing (2014 Apy). These keywords serve as essential building blocks for understanding the broader context of technological advancements in education and health. Conversely, the

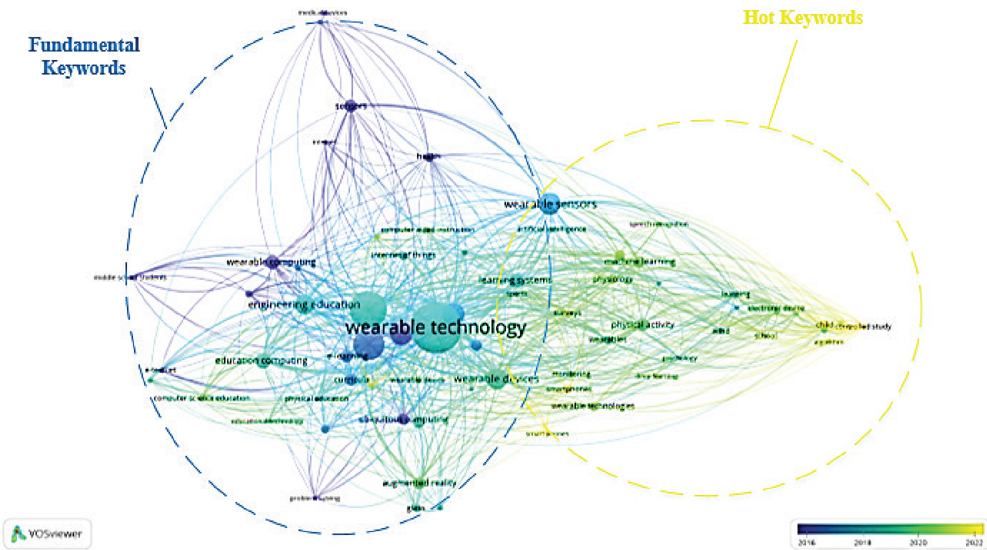


Figure 6. Countries overlay visualization map

second category, highlighted in yellow, comprises emerging and innovative keywords that, as indicated by the topic map analysis, are potentially advancing or declining in relevance over time. This group includes terms such as smartphone (2021 Apy), machine learning (2020 Apy), smartwatch (2020 Apy), ADHD (2014 Apy), physiology (2020 Apy), and physical activity (2019 Apy).

Discussion

This research was formed by analyzing WT scientometrics in schools from 1999 to 2024. The trend of publication of articles was upward (Almusawi et al., 2021b; de-la-Fuente-Robles et al., 2022; Kageyama et al., 2022; Ram, 2024; Tırpan & Semiz, 2022; Yilik, 2023), but with a gentle slope (9 %), and even in recent years, it has faced little attention. However, there have been no successful reviews in recent years, suggesting a need to improve the quality of research or communication in the current academic landscape. For RQ1, trends in publications and citations indicated fluctuating research output and evolving priorities in WT for education, with studies highlighting both the adoption determinants using machine learning (Al-Emran et al., 2023) and pedagogical implications (Chu et al., 2023; Almusawi et al., 2021b). RQ2 was addressed through patterns of international collaboration and institutional contributions, showing that countries such as the USA, UK, China, and Japan have been leading in WT educational research, with varying citation impacts reflecting research influence and regional engagement (Kageyama et al., 2022; Ram, 2024). For RQ3, influential references emphasized innovations in physical education, health monitoring, affective computing, and equity-focused computer science applications (Almusawi et al., 2021a; Fields et al., 2017, 2018; Picard, 2009; Gao et al., 2020), underlining their role in shaping both educational practice and technological development. Finally, RQ4 examined the thematic evolution of WT research, revealing a transition from foundational themes like student engagement and wearable sensors to specialized applications including biosensors, exergames, electronic textiles, and machine learning integration (Lindberg et al., 2016; Meena et al., 2023; Zeagler et al., 2021; AlGerafi et al., 2023), reflecting the growing complexity and integration of advanced technologies in educational contexts.

Among countries, despite the complete dominance of the United States and China (Almusawi et al., 2021b; de-la-Fuente-Robles et al., 2022; Kageyama et al., 2022; Ram, 2024; Tırpan & Semiz, 2022; Yilik, 2023), countries such as India and Japan in publishing articles (Kageyama et al., 2022; Ram, 2024) and Finland, Bahrain, and Turkey in being references have achieved successes that indicate their capabilities and investments in this field (Irani et al., 2024; Shahroz et al., 2021). Among the dependencies, it also seems that in recent years, US universities have had much power (Yilik, 2023), which the University of Ljubljana has broken but has been unable to share. However, previous studies found that Chinese universities were dominant (Ram, 2024). US universities lead in the field of WT thanks to their robust focus on research and innovation (Loncar-Turukalo et al., 2019), as well as substantial financial support from government and private sources (Casselman et al., 2017). Furthermore, the availability of high-quality engineering and computer science programs draws in skilled students and faculty who are dedicated to technological progress (Loizides & Koutsakis, 2017).

Among the leader articles, it should also be noted that Picard's (2009) influential work on affective technology for students with autism emphasizes the importance of emotional learning, while Zimmermann-Niefield and colleagues (2019) and Kireev and colleagues (2021) illustrate the rapid rise of machine learning applications and innovative health monitoring solutions, respectively, indicating a shift towards more engaging and practical STEM education. Contributions from Lindberg and colleagues (2016) and Fields and colleagues (2018) further enrich the discourse by addressing equity in computer science and enhancing physical education through technology, ensuring that diverse learners are engaged. Additionally, studies by Almusawi and colleagues (2021) and Gao and colleagues (2020) highlight the need for teacher readiness and the importance of monitoring student engagement and well-being.

In the essential part, the trend analysis and clustering findings reveal a significant trend in integrating technology within the educational landscape, particularly highlighted by the prominence of WT in Cluster #8 (Tırpan & Semiz, 2022), which has garnered 90 citations. This point indicates a strong interest in how such innovations can enhance learning experiences. Additionally, the focus on student-centered research in Cluster #3 and other themes, such as e-learning and engineering education, underscores a growing emphasis on leveraging technology to improve educational outcomes (Kageyama et al., 2022). The varying silhouette values across clusters also suggest opportunities to refine group dynamics and strategies within the school system, indicating a dynamic and evolving academic environment.

Foundational clusters emphasize human interaction, physical activity, and the integration of WDs, highlighting key terms like ”students,” ”wearable sensors,” and ”teaching” that focus on enhancing educational experiences (Tırpan & Semiz, 2022; Yilik, 2023). In contrast, emerging clusters indicate a shift towards specialized applications, such as ”medical devices” and ”biosensors,” reflecting a growing interest in health monitoring and data-driven insights (Kageyama et al., 2022; Ram, 2024). Additionally, keywords are categorized into foundational concepts, which provide stability in the field, and innovative terms that signify evolving research trends, such as ”smartphone” and ”machine learning” (Ram, 2024).

Conclusion

The article presents several key findings regarding the trends in WT research in schools from 1999 to 2024. There has been a gradual increase (9 %) in the publication of articles on WT, although in recent years, there has been a decline in attention and successful reviews, suggesting a need for improved research quality and communication. The United States and China dominate the field, but countries like India, Japan, Finland, Bahrain, and Turkey also make significant contributions, indicating a diverse global landscape in WT research.

US universities are at the forefront of WT research, supported by substantial funding and high-quality engineering programs, although the University of Ljubljana has shown the potential to break this dominance. Critical studies emphasize emotional learning for students with autism, the rise of machine learning applications, and the integration of technology into STEM education, highlighting a shift toward more engaging educational practices. The research identifies significant trends in technology integration within education, mainly through WT, and emphasizes student-centered research, e-learning, and engineering education. There is growing interest in specialized applications such as medical devices and biosensors, reflecting a shift towards health monitoring and data-driven insights.

One notable limitation of this research is related to temporal constraints, as a substantial portion of the literature reviewed was not published in 2024, despite data extraction occurring after 2025, which may affect the immediacy and relevance of the findings; additionally, the reliance on specific databases such as Scopus, Emerald, and Google Scholar, while extensive, may have excluded other valuable sources, suggesting that the inclusion of supplementary databases could provide broader and more nuanced insights. Another limitation stems from the methodological focus of many of the reviewed studies, which predominantly use quantitative methods, potentially limiting the depth of understanding of the contextual, experiential, and qualitative aspects of WT adoption and use in educational settings. Expanding the scope to encompass a wider array of subject areas, publication types, and mixed-method or qualitative studies could therefore enhance the comprehensiveness, richness, and generalizability of the findings, offering a more balanced understanding of emerging trends, ethical considerations, and practical implications for policy and pedagogical innovation.

Recent articles often devote considerably less attention to the ethical, legal, and social challenges that accompany their implementation—particularly issues surrounding privacy, data security, algorithmic bias, and equitable accessibility. Numerous studies highlight the rapid expansion of WDs for learning, monitoring, and engagement (e.g., Al-Emran et al., 2023; Almusawi, Durugbo, & Bugawa, 2021b; Chu, Garcia, & Rani, 2023), as well as their pedagogical promise across disciplines ranging from physical education (Lindberg et al., 2016) to special needs support (Cheng & Lai, 2020) and STEM learning environments (Fields et al., 2018). However, scholars have argued that the accelerated diffusion of such technologies can amplify risks related to the extraction of personal data, biometric surveillance, and unequal access if these concerns remain unaddressed (Borthwick et al., 2015; Cahyanto et al., 2023; Picard, 2009). Even outside educational contexts, reviews of wearable healthcare and monitoring systems underscore longstanding concerns about the handling of sensitive data and user consent (Baig, Gholamhosseini, & Connolly, 2013; Greiwe & Nyenhuis, 2020; Loncar-Turukalo et al., 2019), yet this literature is rarely integrated into educational analyses. Expanding future reviews to include systematic consideration of ethical and legal frameworks would therefore offer a more balanced and contextualized understanding of wearable technologies in learning environments and would support the development of informed guidance, safeguarding protocols, and responsible implementation recommendations (Almusawi, Durugbo, & Bugawa, 2021a; Ferreira et al., 2021; Vijayan et al., 2021).

Acknowledgements

1. 2025 Zhejiang Provincial Chinese Vocational Education Scientific Research Project ”Research on Artificial Intelligence Empowering the Closed-loop Ecological Construction of Industry-education Integration in Island Vocational Education” (No: ZJCV2025B65);

2. 2025 Zhejiang Vocational Skills Teaching Research Institute Project ”Research on the Path of AI Technology-driven Moral Education-oriented Digital Reading Literacy Improvement” (No: 2025-02-156);

3. 2025 Zhoushan Education Service Center Education Informatization Research Project ”Research on the Integration Path of Generative Artificial Intelligence Empowering Students’ Digital Reading and Moral Cognition” (No: 2025ZSETC02)

References

Al-Emran, M., Al-Nuaimi, M. N., Arpaci, I., Al-Sharafi, M. A., & Anthony Jnr, B. (2023). Towards a wearable education: Understanding the determinants affecting students’ adoption of wearable technologies using machine learning algorithms. *Education and Information Technologies*, *28*(3), 2727–2746. https://doi.org/10.1007/S10639-022-11294-Z/METRICS

AlGerafi, M. A. M., Zhou, Y., Oubibi, M., & Wijaya, T. T. (2023). Unlocking the Potential: A Comprehensive Evaluation of Augmented Reality and Virtual Reality in Education. *Electronics 2023, Vol. 12, Page 3953*, *12*(18), 3953. https://doi.org/10.3390/ELECTRONICS12183953

Almusawi, H. A., Durugbo, C. M., & Bugawa, A. M. (2021a). Innovation in physical education: Teachers' perspectives on readiness for wearable technology integration. *Computers & Education*, *167*, 104185. https://doi.org/10.1016/J.COMPEDU.2021.104185

Almusawi, H. A., Durugbo, C. M., & Bugawa, A. M. (2021b). Wearable Technology in Education: A Systematic Review. *IEEE Transactions on Learning Technologies*, *14*(4), 540–554. https://doi.org/10.1109/TLT.2021.3107459

Baig, M. M., Gholamhosseini, H., & Connolly, M. J. (2013). A comprehensive survey of wearable and wireless ECG monitoring systems for older adults. *Medical and Biological Engineering and Computing*, *51*(5), 485–495. https://doi.org/10.1007/S11517-012-1021-6

Blasco, J., Chen, T. M., Tapiador, J., & Peris-Lopez, P. (2016). A survey of wearable biometric recognition systems. *ACM Computing Surveys*, *49*(3). https://doi.org/10.1145/2968215

Borthwick, A. C., Anderson, C. L., Finsness, E. S., & Foulger, T. S. (2015). Special Article Personal Wearable Technologies in Education: Value or Villain? *Journal of Digital Learning in Teacher Education*, *31*(3), 85–92. https://doi.org/10.1080/21532974.2015.1021982

Cahyanto, I., Pendidikan, M., Pascasarjana, S., & Wiralodra, U. (2023). Privacy Challenges in Using Wearable Technology in Education Literature Review. *Formosa Journal of Applied Sciences*, *2*(6), 909–928. https://doi.org/10.55927/FJAS.V2I6.4272

Can, Y. S., Chalabianloo, N., Ekiz, D., Fernandez-Alvarez, J., Riva, G., & Ersoy, C. (2020). Personal Stress-Level Clustering and Decision-Level Smoothing to Enhance the Performance of Ambulatory Stress Detection with Smartwatches. *IEEE Access*, *8*, 38146–38163. https://doi.org/10.1109/ACCESS.2020.2975351

Casselman, J., Onopa, N., & Khansa, L. (2017). Wearable healthcare: Lessons from the past and a peek into the future. *Telematics and Informatics*, *34*(7), 1011–1023. https://doi.org/10.1016/J.TELE.2017.04.011

Chen, C. (2006). CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. *Journal of the American Society for Information Science and Technology*, *57*(3), 359–377. https://doi.org/10.1002/ASI.20317

Chen, C., & Song, M. (2019). Visualizing a field of research: A methodology of systematic scientometric reviews. *PLoS ONE*, *14*(10). https://doi.org/10.1371/JOURNAL.PONE.0223994

Cheng, S. C., & Lai, C. L. (2020). Facilitating learning for students with special needs: a review of technology-supported special education studies. *Journal of Computers in Education*, *7*(2), 131–153. https://doi.org/10.1007/S40692-019-00150-8/METRICS

Chong, K. P. L., Guo, J. Z., Deng, X., & Woo, B. K. P. (2020). Consumer perceptions of wearable technology devices: Retrospective review and analysis. *JMIR MHealth and UHealth*, *8*(4), e17544. https://doi.org/10.2196/17544

Chu, S. L., Garcia, B. M., & Rani, N. (2023). Research on wearable technologies for learning: a systematic review. *Frontiers in Education*, *8*, 1270389. https://doi.org/10.3389/FEDUC.2023.1270389/BIBTEX

Conderman, G., Van Laarhoven, T., Johnson, J., & Liberty, L. (2021). Wearable technologies for students with disabilities. *Support for Learning*, *36*(4), 664–677. https://doi.org/10.1111/1467-9604.12386

de-la-Fuente-Robles, Y. M., Ricoy-Cano, A. J., Albín-Rodríguez, A. P., López-Ruiz, J. L., & Espinilla-Estévez, M. (2022). Past, Present and Future of Research on Wearable

Technologies for Healthcare: A Bibliometric Analysis Using Scopus. *Sensors*, *22*(22). https://doi.org/10.3390/s22228599

De Canio, F., Martinelli, E., Peruzzini, M., & Cavallaro, S. (2022). Experiencing a Food Production Site Using Wearable Devices: The Indirect Impact of Immersion and Presence in VR Tours. *Sustainability 2022, Vol. 14, Page 3064*, *14*(5), 3064. https://doi.org/10.3390/SU14053064

De Freitas, S., & Levene, M. (2003). Evaluating the development of wearable devices, personal data assistants and the use of other mobile devices in further and higher education institutions. *JISC Technology and Standards Watch Report*, *(TSW030)*, 1-21. http://eprints.bbk.ac.uk/176/

Egeli, G. Z., & Kurgun, H. (2021). Wearable Technologies: Kinesthetic Dimension in Enriching Tourist Experience. *University of South Florida (USF) M3 Publishing*, *18*(9781732127586), 4. https://www.doi.org/10.5038/9781732127586

Ferreira, J. J., Fernandes, C. I., Rammal, H. G., & Veiga, P. M. (2021). Wearable technology and consumer interaction: A systematic review and research agenda. *Computers in Human Behavior*, *118*, 106710. https://doi.org/10.1016/J.CHB.2021.106710

Fields, D. A., Kafai, Y., Nakajima, T., Goode, J., & Margolis, J. (2018). Putting Making into High School Computer Science Classrooms: Promoting Equity in Teaching and Learning with Electronic Textiles in Exploring Computer Science. *Equity & Excellence in Education*, *51*(1), 21–35. https://doi.org/10.1080/10665684.2018.1436998

Fields, D. A., Kafai, Y. B., Nakajima, T. M., & Goode, J. (2017). Teaching practices for making e-textiles in high school computing classrooms. *The 7th Annual Conference on Creativity and Fabrication in, 2017•dl.Acm.Org*, *Part F132090*. https://doi.org/10.1145/3141798.3141804

Gao, N., Shao, W., Rahaman, M. S., & Salim, F. D. (2020). N-Gage: Predicting in-class Emotional, Behavioural and Cognitive Engagement in the Wild. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, *4*(3). https://doi.org/10.1145/3411813

Garzotto, F., Gelsomini, M., Matarazzo, V., Messina, N., & Occhiuto, D. (2018). Designing wearable immersive "social stories" for persons with neurodevelopmental disorder. *SpringerF Garzotto, M Gelsomini, V Matarazzo, N Messina, D OcchiutoUniversal Access in Human-Computer Interaction. Methods, Technologies, and, 2018•Springer*, *10907 LNCS*, 517–529. https://doi.org/10.1007/978-3-319-92049-8_37

Goerlandt, F., & Li, J. (2022). Forty Years of Risk Analysis: A Scientometric Overview. *Risk Analysis*, *42*(10), 2253–2274. https://doi.org/10.1111/RISA.13853

Greiwe, J., & Nyenhuis, S. M. (2020). Wearable Technology and How This Can Be Implemented into Clinical Practice. *Current Allergy and Asthma Reports*, *20*(8), 1–10. https://doi.org/10.1007/S11882-020-00927-3/TABLES/2

Haataja, E., Malmberg, J., & Järvelä, S. (2018). Monitoring in collaborative learning: Co-occurrence of observed behavior and physiological synchrony explored. *Computers in Human Behavior*, *87*, 337–347. https://doi.org/10.1016/J.CHB.2018.06.007

Havard, B., & Podsiad, M. (2020). A meta-analysis of wearables research in educational settings published 2016–2019. *Educational Technology Research and Development*, *68*(4), 1829–1854. https://doi.org/10.1007/S11423-020-09789-Y/METRICS

Irani, K., Siddhanta, M., & Kuriansky, J. (2024). Raising the profile of health technology in the Middle East and North Africa (MENA) region. *Resilient Health: Leveraging Technology* *and Social Innovations to Transform Healthcare for COVID-19 Recovery and Beyond*, 911–928. https://doi.org/10.1016/B978-0-443-18529-8.00077-9

Kageyama, I., Kurata, K., Miyashita, S., Lim, Y., Sengoku, S., & Kodama, K. (2022). A Bibliometric Analysis of Wearable Device Research Trends 2001–2022—A Study on the Reversal of Number of Publications and Research Trends in China and the USA. *International Journal of Environmental Research and Public Health*, *19*(24). https://doi.org/10.3390/ijerph192416427

Kajikawa, Y. (2022). Reframing evidence in evidence-based policy making and role of bibliometrics: toward transdisciplinary scientometric research. *Scientometrics*, *127*(9), 5571–5585. https://doi.org/10.1007/S11192-022-04325-6/METRICS

Kastrin, A., & Hristovski, D. (2021). Scientometric analysis and knowledge mapping of literature-based discovery (1986–2020). *Scientometrics 2021 126:2*, *126*(2), 1415–1451. https://doi.org/10.1007/S11192-020-03811-Z

Kaul, A., & Pooja, P. (2021). Analysis of Prevalence and Effectiveness of Mobile Devices and Wearables in the Domain of Education. *2021 International Conference on Computational Performance Evaluation, ComPE 2021*, 120–125. https://doi.org/10.1109/COMPE53109.2021.9751884

Kim, H., Kwon, Y. T., Lim, H. R., Kim, J. H., Kim, Y. S., & Yeo, W. H. (2021). Recent Advances in Wearable Sensors and Integrated Functional Devices for Virtual and Augmented Reality Applications. *Advanced Functional Materials*, *31*(39), 2005692. https://doi.org/10.1002/ADFM.202005692

Kireev, D., Ameri, S. K., Nederveld, A., Kampfe, J., Jang, H., Lu, N., & Akinwande, D. (2021). Fabrication, characterization and applications of graphene electronic tattoos. *Nature Protocols*, *16*(5), 2395–2417. https://doi.org/10.1038/S41596-020-00489-8

Klopfer, E., Yoon, S., & Rivas, L. (2004). Comparative analysis of Palm and wearable computers for Participatory Simulations. *Journal of Computer Assisted Learning*, *20*(5), 347–359. https://doi.org/10.1111/J.1365-2729.2004.00094.X

Kumari, P., Mathew, L., & Syal, P. (2017). Increasing trend of wearables and multimodal interface for human activity monitoring: A review. *Biosensors and Bioelectronics*, *90*, 298–307. https://doi.org/10.1016/J.BIOS.2016.12.001

Labus, A., Milutinovic, M., Stepanic, Đ., Stevanovic, M., & Milinovic, S. (2015). Wearable computing in e-education. *RUO. Revija Za Univerzalno Odlicnost*, *4*(1), 39. https://www.academia.edu/download/82912624/wearable_comouting_in_e_education.pdf

Lau, W. W. Y., Ngai, G., Chan, S. C. F., & Cheung, J. C. Y. (2009). Learning programming through fashion and design: A pilot summer course in wearable computing for middle school students. *SIGCSE'09 - Proceedings of the 40th ACM Technical Symposium on Computer Science Education*, 504–508. https://doi.org/10.1145/1508865.1509041

Lee, V. R., & Shapiro, R. B. (2019). A Broad View of Wearables as Learning Technologies: Current and Emerging Applications. *Learning in a Digital World: Perspective on Interactive Technologies for Formal and Informal Education*, 113–133. https://doi.org/10.1007/978-981-13-8265-9_6

Lenz, L., Meisen, T., Pomp, A., & Jeschke, S. (2016). How will the Internet of Things and big data analytics impact the education of learning-disabled students? A Concept Paper. *2016 3rd MEC International Conference on Big Data and Smart City, ICBDSC 2016*, 325–331. https://doi.org/10.1109/ICBDSC.2016.7460389

Li, Z., & Karimi, A. (2025). Continuities and Changes: A Trend Analysis of Historical Sociology in the 21st Century. *Sociology Lens*.

Lindberg, R., Seo, J., Learning, T. L.-I. transactions on, & 2016, U. (2016). Enhancing physical education with exergames and wearable technology. *Ieeexplore.Ieee.OrgR Lindberg, J Seo, TH LaineIEEE Transactions on Learning Technologies*, *9*(4), 328–341. https://doi.org/10.1109/TLT.2016.2556671

Loizides, O. S., & Koutsakis, P. (2017). On evaluating the quality of a computer science/computer engineering conference. *Journal of Informetrics*, *11*(2), 541–552. https://doi.org/10.1016/J.JOI.2017.03.008

Loncar-Turukalo, T., Zdravevski, E., da Silva, J. M., Chouvarda, I., & Trajkovik, V. (2019). Literature on wearable technology for connected health: Scoping review of research trends, advances, and barriers. *Journal of Medical Internet Research*, *21*(9), e14017. https://doi.org/10.2196/14017

Mashur, D., Mayarni, Handoko, T., & Rafi, M. (2023). Global Literature Trend on Collaborative Governance (Scientometric Analysis in the Social Sciences Discipline). *Jurnal Ilmiah Peuradeun*, *11*(1), 101–116. https://doi.org/10.26811/PEURADEUN.V11I1.829

McIlwraith, D. G., Pansiot, J., Thiemjarus, S., Lo, B. P. L., & Yang, G. Z. (2008). Probabilistic decision level fusion for real-time correlation of ambient and wearable sensors. *Proc. 5th Int. Workshop on Wearable and Implantable Body Sensor Networks, BSN2008, in Conjunction with the 5th Int. Summer School and Symp. on Medical Devices and Biosensors, ISSS-MDBS 2008*, 117–120. https://doi.org/10.1109/ISSMDBS.2008.4575032

Meena, J. S., Choi, S. Bin, Jung, S. B., & Kim, J. W. (2023). Electronic textiles: New age of wearable technology for healthcare and fitness solutions. *Materials Today Bio*, *19*, 100565. https://doi.org/10.1016/J.MTBIO.2023.100565

Mejia, C., Ciarlante, K., & Chheda, K. (2021). A wearable technology solution and research agenda for housekeeper safety and health. *International Journal of Contemporary Hospitality Management*, *33*(10), 3223–3255. https://doi.org/10.1108/IJCHM-01-2021-0102/FULL/XM

Mill, T., Parikh, S., Allen, A., Dart, G., Lee, D., Richardson, C., Howell, K., & Lewington, A. (2021). Live streaming ward rounds using wearable technology to teach medical students: a pilot study. *BMJ Simulation & Technology Enhanced Learning*, *7*(6), 494. https://doi.org/10.1136/BMJSTEL-2021-000864

Montesinos, L., Santos-Diaz, A., Salinas-Navarro, D. E., & Cendejas-Zaragoza, L. (2022). Experiential Learning in Biomedical Engineering Education Using Wearable Devices: A Case Study in a Biomedical Signals and Systems Analysis Course. *Education Sciences 2022, Vol. 12, Page 598*, *12*(9), 598. https://doi.org/10.3390/EDUCSCI12090598

Motti, V. G. (2020a). Introduction to Wearable Computers. In *Wearable Interaction. Human–Computer Interaction Series* (pp. 1–39). Springer, Cham. https://doi.org/10.1007/978-3-030-27111-4_1

Motti, V. G. (2020b). *Wearable Interaction*. Springer, Cham. https://doi.org/10.1007/978-3-030-27111-4_3

Muñoz-Organero, M., Powell, L., Heller, B., & Sensors, V. H. (2019). Using recurrent neural networks to compare movement patterns in ADHD and normally developing children based on acceleration signals from the wrist and ankle. *Mdpi.ComM Muñoz-Organero, L*

Powell, B Heller, V Harpin, J ParkerSensors, 2019•mdpi.Com, *19*(13). https://doi.org/10.3390/s19132935

Panayi, M., Van De Velde, W., Roy, D., Cakmakci, O., De Paepe, K., & Bernsen, N. O. (1999). Today's stories. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *1707*, 320–323. https://doi.org/10.1007/3-540-48157-5_34

Patel, V., Chesmore, A., Legner, C. M., & Pandey, S. (2022). Trends in Workplace Wearable Technologies and Connected-Worker Solutions for Next-Generation Occupational Safety, Health, and Productivity. *Advanced Intelligent Systems*, *4*(1), 2100099. https://doi.org/10.1002/AISY.202100099

Picard, R. W. (2009). Future affective technology for autism and emotion communication. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1535), 3575–3584. https://doi.org/10.1098/RSTB.2009.0143

Ram, S. (2024). Research Trends in Wearable Devices : A Bibliometric Assessment Research Trends in Wearable Devices : A Bibliometric Assessment. *Fifth International Conference on Science & Technology Metrics (STMet 2024)*. https://doi.org/10.6025/stm/2024/5/147-160

Rawat, K. S., & Sood, S. K. (2021). Emerging trends and global scope of big data analytics: a scientometric analysis. *Quality and Quantity*, *55*(4), 1371–1396. https://doi.org/10.1007/S11135-020-01061-Y/METRICS

Sapargaliyev, D. (2015). Wearables in education: Expectations and disappointments. *Communications in Computer and Information Science*, *559*, 73–78. https://doi.org/10.1007/978-3-662-48978-9_7

Sedighi, M. (2020). Evaluating the impact of research using the altmetrics approach (case study: the field of scientometrics). *Global Knowledge, Memory and Communication*, *69*(4–5), 241–252. https://doi.org/10.1108/GKMC-02-2019-0013/FULL/XML

Shahroz, M., Ahmad, F., Younis, M. S., Ahmad, N., Kamel Boulos, M. N., Vinuesa, R., & Qadir, J. (2021). COVID-19 digital contact tracing applications and techniques: A review post initial deployments. *Transportation Engineering*, *5*, 100072. https://doi.org/10.1016/J.TRENG.2021.100072

Sheikhnejad, Y., & Yigitcanlar, T. (2020). Scientific Landscape of Sustainable Urban and Rural Areas Research: A Systematic Scientometric Analysis. *Sustainability 2020, Vol. 12, Page 1293*, *12*(4), 1293. https://doi.org/10.3390/SU12041293

Shen, X., Li, J., Li, M., & Karimi, A. (2025). A 29-Year (1994–2023) Bibliometrics Analysis of Usage of the Gamification in History Education. *European Journal of Education*, 60(4), e70256.

Sucharitha, G., Tannmayee, B., & Dwarakamai, K. (2022). Revolution in IoT: Smart Wearable Technology. *EAI/Springer Innovations in Communication and Computing*, 407–425. https://doi.org/10.1007/978-3-030-77528-5_21/COVER

Tırpan, E. C., & Semiz, T. (2022). Bibliometric Analysis of Wearable Technology Studies in The Healtcare Industry. *AJIT-e: Academic Journal of Information Technology*, *13*(50), 107–122. https://doi.org/10.5824/ajite.2022.03.001.x

Versteeg, M. F., Hoven, E. A. W. H. van den, & Hummels, C. C. M. (2020). Where fashion, jewellery and wearable technology meet. *Journal of Jewellery Research*, *3*, 82–95.

https://research.tue.nl/en/publications/where-fashion-jewellery-and-wearable-technology-meet

Vijayan, V., Connolly, J., Condell, J., McKelvey, N., & Gardiner, P. (2021). Review of Wearable Devices and Data Collection Considerations for Connected Health. *Sensors 2021, Vol. 21, Page 5589*, *21*(16), 5589. https://doi.org/10.3390/S21165589

Vishkaie, R. (2018). Poster: Can wearable technology improve children's creativity? *UbiComp/ISWC 2018 - Adjunct Proceedings of the 2018 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2018 ACM International Symposium on Wearable Computers*, 279–282. https://doi.org/10.1145/3267305.3267564

Wang, B. (2017). Evaluation of sports visualization based on wearable devices. *Learntechlib. OrgB WangInternational Journal of Emerging Technologies in Learning (IJET), 2017•learntechlib. Org*, *12*(12), 119–126. https://doi.org/10.3991/ijet.v12.i12.7962

Yilik, P. (2023). A Bibliometric Analysis of Wearable Health Technology Research. *Bilge International Journal of Science and Technology Research*, *7*(2), 187–197. https://doi.org/10.30516/bilgesci.1358090

Yin, J., Hinchet, R., Shea, H., & Majidi, C. (2021). Wearable Soft Technologies for Haptic Sensing and Feedback. *Advanced Functional Materials*, *31*(39), 2007428. https://doi.org/10.1002/ADFM.202007428

Zeagler, C., Lish, J., Cheezburger, E., Woo, M., Tynan, K. L., Morton, E., Mannan, S., Christensen, E. L., Eggleston, J., Greenfield, P., Choi, C. L., Gustafsson, A., Holmgren, J., Iyer, A., Chi, M., Gandy, M., Levy, L., & Bolter, J. D. (2021). YOU BETTA WERK: Using Wearable Technology Performance Driven Inclusive Transdisciplinary Collaboration to Facilitate Authentic Learning. *TEI 2021 - Proceedings of the 15th International Conference on Tangible, Embedded, and Embodied Interaction*. https://doi.org/10.1145/3430524.3440622

Zimmermann-Niefield, A., Turner, M., Murphy, B., Kane, S. K., & Shapiro, R. B. (2019). Youth learning machine learning through building models of athletic moves. *Proceedings of the 18th ACM International Conference on Interaction Design and Children, IDC 2019*, 121–132. https://doi.org/10.1145/3311927.3323139

Hongshuai Shi
School of Education, Jiangxi Normal University,
Nanchang, Jiangxi Province, 330022, China
Department of Port Machinery and Chemical Engineering,
Zhoushan Technician College, Zhoushan,
Zhejiang Province, 316012, China
mailto:shihongshuai@126.com
shihongshuai@126.com

Amir Karimi
Department of History, Faculty of Law and Social Sciences,
University of Tabriz, East Azarbaijan, Iran
mailto:amirkarimizanjani1379@gmail.com
amirkarimizanjani1379@gmail.com

Novi trendovi i obrasci u korištenju nosive tehnologije (WT) u školama (1999. - 2024.): scientometrijska perspektiva

Sažetak

U ovome članku ispituju se trendovi u nosivoj tehnologiji (WT) u obrazovanju od 1999. do 2024. godine, koristeći scientometrijski pristup za analizu evolucije istraživanja. Ukupno je iz 165 različitih časopisa izdvojeno 248 originalnih članaka. Ti su članci potom analizirani korištenjem tri specijalizirana softverska alata: CiteSpace, VOSviewer i programski paket R. Tijekom posljednja dva desetljeća broj znanstvenih članaka povećao se za oko 9 %. Međutim, posljednjih godina došlo je do pada pozornosti posvećene recenzijama kao i njihova utjecaja. SAD i Kina predvode istraživanje WT-a, uz značajna sredstva i inženjerske programe, s američkim sveučilištima na čelu. Zemlje poput Indije, Japana, Finske, Bahreina i Turske značajno doprinose, što ukazuje na globalni interes za ovo područje. Ključne studije naglašavaju prednosti emocionalnoga učenja za učenike s autizmom i integraciju strojnoga učenja u WT-u, promičući interaktivno STEM obrazovanje. Nalazi ističu pomak prema pristupima usmjerenima na učenike i specijaliziranim primjenama, poput medicinskih uređaja. U članku se naglašava razvoj krajolika nosive tehnologije u školama i potrebu za kontinuiranim istraživanjem i suradnjom kako bi se poboljšali obrazovni ishodi i stvorila inkluzivna okružja za učenje.

Ključne riječi: *analiza trendova; integracija tehnologije; nosiva tehnologija; obrazovna tehnologija; scientometrija.*

Uvod

Nosiva tehnologija (WT) i nosivi uređaji (WD) brzo su se razvili u bitne alate koji poboljšavaju mnoge aspekte svakodnevnoga života (Chong i sur., 2020.) pružajući korisne značajke koje nadilaze one tradicionalnih računalnih i komunikacijskih uređaja (Ferreira i sur., 2021.; Motti, 2020a). Njihova relevantnost kao bitnih i vrijednih alata u današnje vrijeme dodatno je dokazana njihovom sposobnošću da potpuno transformiraju način na koji komuniciramo, učimo, ostajemo zdravi i putujemo.

Zbirka elektroničkih naprava poznatih kao WT ugrađena je u odjeću ili modne dodatke ili se nosi na tijelu (Meena i sur., 2023). Ovi uređaji nude kupcima udoban pristup informacijama, komunikaciji i funkcionalnosti bez upotrebe ruku zahvaljujući svojim vrhunskim senzorima i tehnologiji (Egeli i Kurgun, 2021). Praćenje kondicije (Greiwe i Nyenhuis, 2020), komunikacija (Ferreira i sur., 2021), virtualna stvarnost (VR) i proširena stvarnost (AR) (Kim i sur., 2021), osobna sigurnost, produktivnost (Patel i sur., 2022), zdravstvena skrb (Mejia i sur., 2021) i moda (Versteeg i sur., 2020) među popularnim su primjenama. Upravljanje zdravstvenim ciljevima u stvarnome vremenu omogućuju fitness narukvice, pametni satovi i svijetla odjeća (Sucharitha i sur., 2022), koji prate otkucaje srca, potrošene kalorije, obrasce spavanja i tjelesnu aktivnost. Dok VR i AR slušalice omogućuju impresivna iskustva (De Canio i sur., 2022), pametni satovi i naočale omogućuju korisnicima pristup informacijama bez upotrebe ruku (Motti, 2020b). Dakle, WT će nastaviti pronalaziti dodatne primjene u širem rasponu industrija kako se bude razvijao.

Zbog ponude kreativnih metoda za poboljšanje poučavanja i učenja (Almusawi i sur., 2021a; Havard i Podsiad, 2020), WT ima potencijal potpuno transformirati obrazovni sustav (Almusawi i sur., 2021a). Prikuplja podatke o učenicima (Vijayan i sur., 2021), pruža prilagođene povratne informacije i stvara zanimljive virtualne svjetove (Yin i sur., 2021). Osim toga, WT podržava učenike s teškoćama u razvoju, omogućuje suradničko učenje (Zeagler i sur., 2021), prevodi jezike u stvarnom vremenu i prikuplja točne podatke o pojedinačnim učenicima (Al-Emran i sur., 2023). Također daju neposredne povratne informacije o strategijama poučavanja i upravljanju učionicom učiteljima upisanim u programe pripreme učitelja (Mill i sur., 2021). Iako WT u obrazovanju još nije dosegao svoj puni potencijal, ovi primjeri pokazuju koliko je važno imati individualizirana, dinamična i zanimljiva okružja za učenje i za učitelje i za učenike.

Stoga je praktično, iskustveno učenje također moguće ostvariti putem rada u radnim okružjima (WD), čime se učenicima omogućuje izravno uključivanje u obrazovni sadržaj (Montesinos i sur., 2022). Štoviše, ovaj pristup potiče aktivno istraživanje, kritičko razmišljanje i dublje razumijevanje složenih koncepata (AlGerafi i sur., 2023), a također podržava posebno obrazovanje i raznolike potrebe učenja (Cheng i Lai, 2020), pružajući prilagodbu učenicima s različitim stilovima i sposobnostima učenja (Conderman i sur., 2021). Kako bi se izgradilo povjerenje u WD u obrazovnim okružjima, škole moraju uspostaviti snažne politike i postupke za zaštitu podataka i privatnosti učenika, pridržavajući se zakona kao što su FERPA i COPPA (Cahyanto i sur., 2023). Precizne smjernice za prikupljanje, pohranu i korištenje podataka također su ključne, a otvorena komunikacija s roditeljima, edukatorima i učenicima je bitna. Prepoznajući važnost i inovativnost WD-a u obrazovanju, postaje očita potreba za ispitivanjem broja članaka objavljenih u ovome području, što upućuje na potrebu provođenja scientometrijske analize. Ipak, nova istraživačka područja, istraživački razgovori i postojeći trendovi u ovome području nisu temeljito proučeni, unatoč brojnim preglednim člancima.

Osim mapiranja postojećega znanja (Kastrin i Hristovski, 2021) i identificiranja značajnih istraživača, trendova (Rawat i Sood, 2021) i novih područja fokusa (Goerlandt i Li, 2022), scientometrijsko istraživanje ključno je za razumijevanje istraživačkoga krajolika, identificiranje istraživačkih praznina (Sheikhnejad i Yigitcanlar, 2020), utjecaj na političke odluke, poticanje suradnje (Mashur i sur., 2023) i procjenu utjecaja istraživanja (Sedighi, 2020). Također pomaže u postavljanju istraživačkih prioriteta i stvaranju politika za integraciju TR-a u učionicu (Kajikawa, 2022.). Sektor se stalno mijenja, a scientometrijska analiza pomaže u praćenju trendova TR u obrazovanju i služi kao standard za analizu proizvodnje, utjecaja i utjecaja istraživanja. Iz toga razloga, scientometrijsko istraživanje ključno je za unaprjeđenje TR-a u obrazovanju.

Pregled literature

Prema Chuu i sur. (2023), iako se WT poboljšao, obrazovanje ih nije uključilo u svoj kurikul. Većina evaluacija usredotočuje se na osnovne značajke nosivih uređaja (Kumari i sur., 2017), a ne na tržišne niše poput zdravstvene zaštite (Baig i sur., 2013), asistivne tehnologije ili sigurnosti (Blasco i sur., 2016). Neka istraživanja i pregledni članci o nosivim uređajima za učenje identificirani su pretraživanjem literature (Borthwick i sur., 2015; De Freitas i Levene, 2003; Labus i sur., 2015). To uključuje izvješće o nosivim uređajima, studiju o Google Glassu koju je proveo Sapargaliyev (2015) i istraživanje Attallaha i Ilagurea (2018) koje se bavi troškovima, upotrebljivošću, ometanjem, tehnološkom tjeskobom i zahtjevom da se nosivi uređaji povežu s pametnim telefonima. U eseju Leeja i Shapira (2019) ispituju se trenutačne inicijative WT-a i ističe njihov obrazovni potencijal. Ispituje se nekoliko metoda pomoći, kao što su digitalna integracija, igranje uloga, obavijesti, snimanje tjelesnoga iskustva i osobno izražavanje. Najbolji uređaji identificirani u metaanalizi istraživanja Harvarda i Podsiada (2020) bili su pametni satovi, *fitness trackeri* i zasloni koji se montiraju na glavu. Metode, teorije, vrste, primjene i istraživački fokusi WT-a u obrazovanju ispitani su u pregledu literature Almusawija i suradnika (2021). Raspravlja se o budućim putevima istraživanja i teorijskim temeljima. Na kraju, Chu i suradnici (2023) nude okvir od pet bitnih komponenti, navode sedam načina na koje bi nosivi uređaji mogli podržati učenje i identificiraju neistražena istraživačka područja na temelju svojega pregleda.

Osim toga, kao scientometrijska studija, Cheng i Yao (2019) dijele sličnosti s referenciranim člancima u svojem fokusu na procjenu utjecaja i trendova unutar korištenja VR-a za učenje engleskoga jezika. Studija koristi Citespace za ispitivanje istraživačkih trendova u VR-ima. Učionice virtualne stvarnosti (VR) i uključivanje mobilnoga učenja dva su razvoja identificirana u nastavi engleskoga jezika. Prema istraživanju, VR će imati više obrazovnih mogućnosti u budućnosti.

Publikacije o WT-u u obrazovanju uključuju neke nedostatke kao što su loše tehnike uzorkovanja, nejasan vremenski raspon i nedostatak preciznosti u postupcima (Almusawi i sur., 2021b; de-la-Fuente-Robles i sur., 2022; Kageyama i sur., 2022; Ram, 2024; Tırpan i Semiz, 2022; Yilik, 2023). Ovi problemi mogu ograničiti praktični značaj istraživanja dovodeći u sumnju valjanost i pouzdanost njegovih rezultata. Kako bi se poboljšala valjanost, relevantnost i primjenjivost ovih nalaza, ovim istraživanjem snažno se naglašava iskreno izvještavanje o postupcima uzorkovanja, jasnu prezentaciju metodologije i definiciju vremenskoga raspona. Zatim, cilj ovoga članka jest ispitati scientometriju članaka objavljenih u WT-u te se pritom usmjeriti na sljedeća istraživačka pitanja:

RQ1. Koji se obrasci mogu uočiti u ukupnom trendu objavljivanja članaka i učestalosti citiranja unutar područja?

RQ2. Kako se trendovi objavljivanja razlikuju među različitim zemljama i institucijama te kakve implikacije ti trendovi imaju na globalnu istraživačku suradnju?

RQ3. Koje se vrste referenci pretežno koriste unutar sustava članaka i kako doprinose razvoju područja?

RQ4. Koje su se značajne promjene dogodile u trendovima područja i mapi predmeta posljednjih godina i kako te promjene odražavaju razvoj znanstvenoga područja?

Metodologija

Strategija pretraživanja i prikupljanje podataka

U ovoj studiji korišteni su podatci iz baze podataka Web of Science (WoS), s izdvajanjem provedenim 10. siječnja 2025., kako bi se sustavno odgovorilo na definirana istraživačka pitanja. WoS je odabran u odnosu na alternativne baze podataka, poput Scopusa, prvenstveno zbog širega i sveobuhvatnijega pokrivanja relevantne literature u okviru istraživanja udžbenika povijesti, čime se osigurava bogatiji i reprezentativniji skup podataka. Ovaj izbor u skladu je s namjerom izrade detaljnoga, interdisciplinarnoga profila citiranja, čime se olakšava nijansirano razumijevanje obrazaca znanstvene komunikacije. Organizacija podataka upravljana je pomoću Microsoft Excela, dok su napredni alati za bibliometrijsku vizualizaciju i analizu mreže - uključujući CiteSpace, VOSviewer i Bibliometrix - korišteni za generiranje sofisticiranih mrežnih dijagrama, u skladu s metodologijama usvojenim u prethodnim bibliometrijskim istraživanjima. Oslanjanje na ove suvremene analitičke alate odražava spoznaju da su se tradicionalni deskriptivni bibliometrijski pristupi pokazali neadekvatnima u rješavanju složenih i stalno promjenjivih izazova svojstvenih ovome istraživačkom području (Li i Karimi, 2025). Kako bi se osigurala metodološka strogost, utvrđeni su eksplicitni kriteriji uključivanja. Proces ekstrakcije podataka iz baze podataka Scopus koristio je specifičnu strategiju pretraživanja koja je uključivala sljedeće ključne riječi: „nosiva tehnologija*" ILI „nosivi uređaj*" ILI „nosivi elektron*" ILI „nosivi senzor*" ILI „nosivo računalo*" I „educirati*" ILI „poučavati*" ILI „instruirati*" ILI „učiti*" ILI „osposobljavati*" I škola*" I NE isključujući „životinja*" ILI „pacijent*" ILI „odrasla osoba*" ILI „medicinska škola*" ILI „medicinsko obrazovanje*" (slika 1).

Proces prikupljanja podataka slijedio je sustavnu, višefaznu strategiju filtriranja, kao što je prikazano na Slici 1, počevši s odabirom baze podataka Scopus kao primarnoga izvora zbog njezinoga sveobuhvatnog indeksiranja recenziranih međunarodnih istraživanja. Na polja Naslov, Sažetak i Ključne riječi primijenjen je napredni upit za pretraživanje koji kombinira pojmove vezane uz nosivu tehnologiju i obrazovanje što je dalo početni skup od 388 zapisa. Naknadni korak poboljšanja uključivao je isključivanje publikacija koje sadrže pojmove povezane s neobrazovnim ili kliničkim kontekstima, poput studija vezanih uz životinje, pacijente ili medicinske fakultete čime je smanjen skup podataka na 308 zapisa. Kako bi se dodatno osigurala konceptualna usklađenost s fokusom studije, primijenjen je filtar predmetnoga područja kojim su isključena istraživanja kategorizirana prema medicinskim područjima, čime je eliminirano dodatnih 50 članaka tako da je ukupan broj članaka 258. Sljedeća faza uključivala je ograničavanje skupa podataka na prihvaćene akademske formate publikacija - konferencijske radove, članke u časopisima, poglavlja u knjigama i recenzije konferencija - uklanjanjem pet zapisa i rezultatom revidiranoga ukupnog broja od 253. Zatim je primijenjen jezični filtar, ograničavajući korpus na publikacije na engleskome jeziku kako bi se osigurala analitička dosljednost, što je rezultiralo isključivanjem tri dodatna teksta. Konačno, provedena je ručna provjera relevantnosti kako bi se uklonili zapisi koji, unatoč ispunjavanju tehničkih kriterija pretraživanja, nisu bili suštinski povezani s nosivim tehnologijama u obrazovnim okružjima, čime su uklonjene još dvije stavke i dobiven konačni broj od 248 publikacija, izdvojenih u CSV, RI, Plain Text i BibTeX formatima datoteka (Shen i sur., 2025). Ovaj sustavni proces ekstrakcije i odabira podataka naglašava predanost studije metodološkoj preciznosti i stvaranju robusnih, generalizirajućih uvida u razvojni krajolik obrazovnoga aspekta istraživanja WT-a.

Slika 1

Softver za bibliografsko mapiranje

Disciplina scientometrije koristi niz bitnih softverskih aplikacija za analizu i vizualizaciju podataka. Značajni alati uključuju Microsoft Excel (2013), CiteSpace (6.3.1), VOSviewer (1.6.20) i paket Bibliometrix (3.1.4), koji funkcionira unutar R programskoga okružja (3.6.3). Ovi softverski programi ključni su u bibliometriji, a svaki pruža jedinstvene funkcionalnosti koje rješavaju različite analitičke zahtjeve (Slika 2). Zajedno, kombinirana upotreba Excela, CiteSpacea, VOSviewera i Bibliometrixa omogućila je sveobuhvatnu identifikaciju obrazaca objavljivanja, intelektualnih struktura i tematskih trendova unutar skupa podataka.

Slika 2

Rezultati

Primarne informacije

Tablica 1

Slika 3

Slika 3 otkrila je fluktuirajući trend u broju objavljenih članaka i prosječnom ukupnom broju citata po članku (MeanTCperArt). U početku, 1999. godine, bila su dva članka s prosječnim citiranjem od 14,5, ali u sljedećim godinama došlo je do značajnoga pada, bez objavljenih članaka od 2000. do 2002. Blagi oporavak dogodio se 2003. s 1 člankom, ali tek se 2005. godine izlaz stabilizirao, iako s niskim brojem citata. Od 2007. do 2014.

godine došlo je do postupnoga povećanja članaka i citata koji je dosegao vrhunac 2015. godine s 22 članka i prosječnim citiranjem od 16,86. Međutim, nakon ovoga vrhunca, broj objavljenih članaka ostao je relativno visok, ali s primjetnim padom utjecaja citata, posebno 2022. i 2023. godine, kada su prosječni citati pali na 4,3 odnosno 2,84. 2024. pokazuje daljnji pad utjecaja citata, s prosjekom od samo 0,4 citata po članku. Dok se volumen publikacija povećavao tijekom godina, čini se da se utjecaj citata značajno smanjio u kasnijim godinama, što sugerira potencijalnu potrebu za poboljšanjem kvalitete istraživanja ili relevantnosti u trenutačnom akademskom okružju.

Tablica 1 prikazuje snažan akademski učinak, s 248 dokumenata iz 165 časopisa i knjiga. Godišnja stopa rasta od 9,65 % ukazuje na zdrav porast istraživačke aktivnosti tijekom godina. U prosjeku, dokumenti su stari 6,71 godina, što sugerira kombinaciju nedavnih i etabliranih istraživanja. Svaki dokument u prosjeku ima 12,17 citata, što odražava njegov utjecaj unutar akademske zajednice. Prisutnost 1757 ključnih riječi Plus i 785 ključnih riječi autora ističe raznolik raspon tema. S 867 autora koji doprinose opusu radova, uključujući 29 samostalnih autora, suradnja je očita, što pokazuje prosjek od 3,88 suautora po dokumentu i stopa međunarodnih suautorstva od 16,13 %.

Vodeće zemlje, pripadnosti i članci

Tablica 2

Tablica 2 (dio A) ilustrira raznolik raspon povezanosti, pri čemu Sveučilište u Ljubljani prednjači s osam dokumenata, što ukazuje na snažnu prisutnost u ovome području. Slijede neke istaknute institucije iz Sjedinjenih Država, uključujući Sveučilište Stanford, Sveučilište Teksasa u Austinu i Sveučilište Kalifornije, od kojih svaka doprinosi s 5 do 6 dokumenata. Značajno je da Sveučilište Britanske Kolumbije i Sveučilište Maryland također imaju solidnu zastupljenost, sa 6, odnosno 5 radova. Na međunarodnoj razini, East China Normal University i Aarhus University doprinose raznolikosti istraživačkoga uzorka, ističući globalni interes za istraživanje radne tehnike. Sveukupno, informacije sugeriraju snažan angažman sjevernoameričkih i europskih institucija, s ključnim doprinosom slovenskoga Sveučilišta u Ljubljani. Dijelovi B i C pružili su komparativnu analizu akademskoga učinka i utjecaja citata povezanih s radnom tehnikom u školama u različitim regijama. SAD prednjači sa 147 dokumenata i 667 citata, za prosjek od 20,80 citata po članku, što ukazuje na snažnu akademsku prisutnost. Kina slijedi sa 74 dokumenta i 243 citata, što daje niži prosjek od 9,30 citata po članku, što pak sugerira manji utjecaj po radu. Japan, s 21 dokumentom, ima visoku prosječnu stopu citiranja od 35,30, što ukazuje na to da se članci japanskih istraživača često citiraju unatoč manjem broju citata. U Europi, Španjolska i Italija imaju po 20 dokumenata, ali prosječni broj citata Španjolske od 17,10 niži je od talijanskih 23,80, što sugerira da talijanski radovi ima veći utjecaj. Ujedinjeno Kraljevstvo, sa samo 17 dokumenata, ističe se impresivnim prosjekom od 64,00 citata, što naglašava njegov utjecajni doprinos. Kanada i Njemačka pokazuju niže rezultate i prosjeke citata, dok Australija ima najmanje dokumenata (12), ali održava respektabilan prosjek od 18,70. Sveukupno, podatci ilustriraju različite razine akademske produktivnosti i utjecaja citata, pri čemu su SAD i Ujedinjeno Kraljevstvo identificirani kao zemlje s najvećim doprinosom.

Reference vođa

Tablica 3

Tablica 3 prikazuje raznolik raspon doprinosa koji ističu utjecaj tehnologije na učenje i poučavanje. Picard (2009) ističe se s najvećim ukupnim citatima (TC) od 162, fokusirajući se na učinkovite tehnologije za podršku učenicima s autizmom, sa značajnim implikacijama za emocionalno učenje. Zimmermann-Niefield i sur. (2019) slijede ga usko sa 118 citata i izvanrednim TC-om godišnje od 16,86, što ukazuje na brzi porast relevantnosti zbog njihovog istraživanja primjene strojnoga učenja u obrazovanju. Kireev i sur. (2021) također izvještavaju o visokom TC-u godišnje (16,80) u svojemu radu o elektroničkim tetovažama od grafena, što sugerira inovativne primjene praćenja zdravlja u školama. Ostali značajni članci uključuju Lindberga i sur. (2016) i Fieldsa i sur. (2018), koji naglašavaju važnost tjelesnoga odgoja, odnosno jednakosti u području informatike, uz ostvarivanje solidnih normaliziranih stopa citiranja. Almusawi i sur. (2021) te Gao i sur. (2020) doprinose raspravi o spremnosti učitelja i angažmanu učenika, odražavajući trenutačne obrazovne prioritete. Sveukupno, ovi članci naglašavaju transformativni potencijal WT-a za poboljšanje obrazovnih iskustava, promicanje uključivosti i rješavanje problema mentalnoga zdravlja, a istovremeno ukazuju na rastući interes za to područje, što dokazuju rastuće stope citiranosti posljednjih godina.

Integracija vježbe za učenje (WT) u obrazovne okvire istražena je u raznim studijama, a svaka ističe njezin transformativni potencijal. Picard (2009) istražuje afektivnu tehnologiju za autizam, ukazujući da nosiva elektronika može podržati emocionalnu komunikaciju za učenike s autizmom. Zimmermann-Niefield i sur. (2019) naglašavaju ulogu nosive elektronike u poučavanju strojnoga učenja praktičnom primjenom, čineći STEM obrazovanje zanimljivijim. Kireev i sur. (2021) istražuju elektroničke tetovaže od grafena i predlažu inovativne primjene za praćenje zdravlja u obrazovnim kontekstima. Lindberg i sur. (2016) raspravljaju o poboljšanju tjelesnoga odgoja putem vježbi i WT-a, što može povećati angažman učenika u tjelesnoj aktivnosti. Fields i sur. (2018) raspravljaju o korištenju elektroničkoga tekstila u srednjoškolskoj informatici za promicanje jednakosti, pokazujući kako praktično učenje može angažirati različite učenike. Haataja i sur. (2018) istražuju odnos između opaženih ponašanja i fiziološke sinkronizacije u suradničkom učenju, ukazujući da WT može poboljšati grupne interakcije. Klopfer i sur. (2004) ističu učinkovitost rada s vježbama (WD) u participativnim simulacijama, promičući aktivna iskustva učenja. Almusawi i sur. (2021) ispituju spremnost učitelja za uključivanje WD-a u tjelesni odgoj, otkrivajući da, iako nastavnici vide njegove koristi, zabrinutost zbog obuke i resursa i dalje postoji, što naglašava potrebu za profesionalnim razvojem. Gao i sur. (2020) predstavljaju sustav za predviđanje emocionalnoga i kognitivnoga angažmana u učionicama, koji može pomoći u prilagođavanju nastavnih strategija kako bi se poboljšala uključenost učenika. Konačno, Can i sur. (2020) usredotočuju se na pametne satove za praćenje osobne razine stresa, sugerirajući da takva tehnologija može pomoći nastavnicima da proaktivno rješavaju pitanja dobrobiti i mentalnoga zdravlja učenika.

Analiza trendova i klastera

Slika 4

Slika 4 prikazuje raznoliko grupiranje članova, s najvećim klasterom (#0) koji se sastoji od 40 članova i vrijednošću siluete od 0,782, što ukazuje na umjerenu koheziju. Drugi najveći klaster (#1) također ima 40 članova, ali ima višu vrijednošću siluete od 0,939 što sugerira da je izrazitiji i dobro definiran. Sljedeći klasteri variraju u veličini i vrijednostima siluete, s tim da peti klaster (#4) pokazuje visoku vrijednost siluete od 0,968, što ukazuje na snažnu odvojenost od ostalih klastera. Značajno je da najmanji klaster (#11) ima samo pet članova, ali postiže impresivnu vrijednost siluete od 0,994, što ističe njegovu jasnu razliku.

Tablica 4

Tablica 4 s brojem citata u različitim klasterima ističe važnost radne aktivnosti (WD), koja se ističe u klasteru #8 s impresivnih 90 citata, što ukazuje na njezin značajan utjecaj u tome području. Klaster #3, koji se fokusira na studente, akumulira 60 citata, što naglašava važnost istraživanja usmjerenoga na studente u obrazovnim kontekstima. Klaster #4, koji uključuje prijenosna računala, također pokazuje snažnu relevantnost s 48 citata, dok nosivi senzori u klasteru #5 i poučavanje u klasteru #8 dijele četvrto mjesto s po 31 citata. Druge značajne teme uključuju radne aktivnosti i inženjersko obrazovanje, s naglaskom na integraciji tehnologije u okružjima za učenje. Prisutnost različitih tema poput tjelesne aktivnosti, e-učenja i obrazovnoga računalstva u klasterima sugerira bogatu interakciju između tehnologije i obrazovanja, što odražava trenutačne trendove i interese za poboljšanje iskustava učenja.

Slika 5

Tematski sustav rada s djecom u školama otkriva bogatu interakciju između utvrđenih motoričkih tema i novih trendova (Slika 5). Skupine 1 i 2 ističu temeljne aspekte rada s djecom, fokusirajući se na ljudsku interakciju, tjelesnu aktivnost i integraciju uređaja za rad s djecom u obrazovne okvire. Ključni pojmovi poput „učenik", „nosivi senzori" i „poučavanje" naglašavaju naglasak na poboljšanju iskustava učenja putem tehnologije. Nasuprot tome, skupine 3 i 4 odražavaju pomak prema specijaliziranijim i inovativnijim primjenama, poput „medicinski uređaji", „senzorske mreže" i „biosenzori", što ukazuje na rastući interes za praćenje zdravlja i uvide temeljene na podatcima unutar obrazovnih konteksta. Ova tematska evolucija sugerira da, iako tradicionalne obrazovne prakse ostaju vitalne, postoji značajan pomak prema korištenju naprednih tehnologija za poticanje angažmana, podršku raznolikim potrebama učenja i promicanje opće dobrobiti učenika.

Slika 6

Analiza pokrivenosti (Slika 6) pokazuje da se ključne riječi mogu kategorizirati u dvije različite skupine. Prva kategorija, predstavljena svijetloplavom bojom, obuhvaća temeljne i potporne koncepte koji su stekli važnost u ovome području. Ova skupina uključuje pojmove kao što su nosivo računalstvo (2016. godina), nosivi senzori (2017. godina objave), WT (2018. godina), senzori (2014. godina) i sveprisutno računalstvo (2014. godina). Ove ključne riječi služe kao bitni građevni blokovi za razumijevanje širega konteksta tehnološkoga napretka u obrazovanju i zdravstvu. Suprotno tome, druga kategorija, označena žutom bojom, obuhvaća ključne riječi u nastajanju i inovativne koje, kako je naznačeno analizom tematske mape, potencijalno s vremenom rastu ili opadaju u relevantnosti. Ova skupina uključuje pojmove kao što su pametni telefon (2021. godina), strojno učenje (2020. godina), pametni sat (2020. godina), ADHD (2014. godina), fiziologija (2020. godina) i tjelesna aktivnost (2019. godina).

Diskusija

Ovo istraživanje nastalo je analizom scientometrije rotacijskoga učenja u školama od 1999. do 2024. Trend objavljivanja članaka bio je uzlazni (Almusawi i sur., 2021b; de-la-Fuente-Robles i sur., 2022; Kageyama i sur., 2022; Ram, 2024; Tırpan i Semiz, 2022; Yilik, 2023), ali s blagim nagibom (9 %), te čak i posljednjih godina naišao je na malo pažnje. Međutim, posljednjih godina nije bilo uspješnih pregleda što sugerira potrebu za poboljšanjem kvalitete istraživanja ili komunikacije u trenutačnom akademskom okružju. Za RQ1, trendovi u publikacijama i citatima ukazivali su na fluktuirajuće istraživačke rezultate i promjenjive prioritete u WT-u za obrazovanje, pri čemu su studije isticale i odrednice usvajanja korištenjem strojnoga učenja (Al-Emran i sur., 2023) i pedagoške implikacije (Chu i sur., 2023; Almusawi i sur., 2021b). RQ2 je obrađen putem obrazaca međunarodne suradnje i institucionalnih doprinosa, pokazujući da su zemlje poput SAD-a, Ujedinjenog Kraljevstva, Kine i Japana prednjačile u istraživanju WT-a u obrazovanju, s različitim utjecajima citiranja koji odražavaju utjecaj istraživanja i regionalni angažman (Kageyama i sur., 2022; Ram, 2024). Za RQ3, utjecajni izvori naglasili su inovacije u tjelesnom odgoju, praćenju zdravlja, afektivnom računalstvu i primjenama računalnih znanosti usmjerenima na jednakost (Almusawi i sur., 2021a; Fields i sur., 2017, 2018; Picard, 2009; Gao i sur., 2020), naglašavajući njihovu ulogu u oblikovanju obrazovne prakse i tehnološkoga razvoja. Konačno, RQ4 ispitao je tematsku evoluciju istraživanja strojnoga učenja, otkrivajući prijelaz s temeljnih tema poput angažmana učenika i nosivih senzora na specijalizirane primjene, uključujući biosenzore, vježbe, elektronički tekstil i integraciju strojnoga učenja (Lindberg i sur., 2016; Meena i sur., 2023; Zeagler i sur., 2021; AlGerafi i sur., 2023), što odražava rastuću složenost i integraciju naprednih tehnologija u obrazovnim kontekstima.

Među zemljama, unatoč potpunoj dominaciji Sjedinjenih Američkih Država i Kine (Almusawi i sur., 2021b; de-la-Fuente-Robles i sur., 2022; Kageyama i sur., 2022; Ram, 2024; Tırpan i Semiz, 2022; Yilik, 2023), zemlje poput Indije i Japana u objavljivanju članaka (Kageyama i sur., 2022; Ram, 2024) te Finske, Bahreina i Turske u referencama postigle su uspjehe koji ukazuju na njihove sposobnosti i ulaganja u ovome području (Irani i sur., 2024; Shahroz i sur., 2021). Među ovisnostima, čini se da su posljednjih godina američka sveučilišta imala veliku moć (Yilik, 2023) koju je Sveučilište u Ljubljani slomilo, ali nije moglo podijeliti. Međutim, prethodne studije otkrile su da su kineska sveučilišta bila dominantna (Ram, 2024). Američka sveučilišta prednjače u području tehnološkoga razvoja zahvaljujući snažnom fokusu na istraživanje i inovacije (Loncar-Turukalo i sur., 2019), kao i značajnoj financijskoj potpori vlade i privatnih izvora (Casselman i sur., 2017). Nadalje, dostupnost visokokvalitetnih inženjerskih i računalnih programa privlači vješte studente i nastavnike koji su posvećeni tehnološkom napretku (Loizides i Koutsakis, 2017).

Među vodećim člancima treba napomenuti i da Picardov (2009) utjecajni rad o afektivnoj tehnologiji za učenike s autizmom naglašava važnost emocionalnoga učenja, dok Zimmermann-Niefield i sur. (2019) i Kireev i sur. (2021) ilustriraju brzi porast aplikacija strojnoga učenja, odnosno inovativnih rješenja za praćenje zdravlja što ukazuje na pomak prema angažiranijem i praktičnijem STEM obrazovanju. Doprinosi Lindberga i sur. (2016) i Fieldsa i sur. (2018) dodatno obogaćuju diskurs adresiranjem jednakosti u računalnim znanostima i unaprjeđenjem tjelesnoga odgoja putem tehnologije, osiguravajući da su uključeni različiti učenici. Osim toga, studije Almusawija i sur. (2021) i Gaoa i sur. (2020) ističu potrebu za spremnošću učitelja i važnost praćenja angažmana i dobrobiti učenika.

U bitnom dijelu, analiza trendova i nalazi grupiranja otkrivaju značajan trend u integraciji tehnologije unutar obrazovnoga konteksta posebno istaknut istaknutošću WT-a u Klasteru #8 (Tırpan i Semiz, 2022), koji je prikupio 90 citata. Ovo ukazuje na snažan interes za to kako takve inovacije mogu poboljšati iskustva učenja. Osim toga, fokus na istraživanje usmjereno na studente u Klasteru #3 i druge teme, poput e-učenja i inženjerskoga obrazovanja, stavlja sve veći naglasak na iskorištavanju tehnologije za poboljšanje obrazovnih ishoda (Kageyama i sur., 2022). Različite vrijednosti siluete među klasterima također sugeriraju mogućnosti za poboljšanje grupne dinamike i strategija unutar školskoga sustava, što ukazuje na dinamično i promjenjivo akademsko okružje.

Temeljni klasteri naglašavaju ljudsku interakciju, tjelesnu aktivnost i integraciju uređaja za rad s pokretima, ističući ključne pojmove poput „studenat", „nosivi senzori" i „poučavanje" koji se usredotočuju na poboljšanje obrazovnih iskustava (Tırpan i Semiz, 2022; Yilik, 2023). Nasuprot tome, novi klasteri ukazuju na pomak prema specijaliziranim primjenama, poput „medicinskih uređaja" i "biosenzora", što odražava rastući interes za praćenje zdravlja i uvide temeljene na podatcima (Kageyama i sur., 2022; Ram, 2024). Osim toga, ključne riječi kategorizirane su u temeljne koncepte, koji pružaju stabilnost u području, i inovativne pojmove koji označavaju razvoj istraživačkih trendova, poput „pametnoga telefona" i „strojnoga učenja" (Ram, 2024).

Zaključak

Članak predstavlja nekoliko ključnih nalaza o trendovima u istraživanju WT-a u školama od 1999. do 2024. godine. Došlo je do postupnoga porasta (9 %) u objavljivanju članaka o WT-u, iako je posljednjih godina došlo do pada pažnje i uspješnih recenzija, što sugerira potrebu za poboljšanjem kvalitete istraživanja i komunikacije. Sjedinjene Američke Države i Kina dominiraju tim područjem, ali zemlje poput Indije, Japana, Finske, Bahreina i Turske također daju značajan doprinos, što ukazuje na raznolik globalni kontekst u istraživanju WT-a.

Američka sveučilišta prednjače u istraživanju WT-a, uz značajna sredstva i visokokvalitetne inženjerske programe, iako je Sveučilište u Ljubljani pokazalo potencijal za prekid te dominacije. Kritičke studije naglašavaju emocionalno učenje za studente s autizmom, porast primjene strojnoga učenja i integraciju tehnologije u STEM obrazovanje, ističući pomak prema angažiranijim obrazovnim praksama. Istraživanje identificira značajne trendove u integraciji tehnologije unutar obrazovanja, uglavnom putem WT-a te naglašava istraživanje usmjereno na studente, e-učenje i inženjersko obrazovanje. Postoji sve veći interes za specijalizirane primjene poput medicinskih uređaja i biosenzora, što odražava pomak prema praćenju zdravlja i uvidima temeljenim na podatcima.

Jedno značajno ograničenje ovoga istraživanja povezano je s vremenskim ograničenjima jer znatan dio pregledane literature nije objavljen 2024. godine, unatoč ekstrakciji podataka koja se dogodila nakon 2025. godine, što može utjecati na neposrednost i relevantnost nalaza. Osim toga, oslanjanje na specifične baze podataka poput Scopusa, Emerald i Google Scholara, iako opsežno, moglo je isključiti druge vrijedne izvore, što sugerira da bi uključivanje dodatnih baza podataka moglo pružiti šire i nijansiranije uvide. Drugo ograničenje proizlazi iz metodološkoga fokusa mnogih pregledanih studija, koje pretežno koriste kvantitativne metode, što potencijalno ograničava dubinu razumijevanja kontekstualnih, iskustvenih i kvalitativnih aspekata usvajanja i korištenja WT-a u obrazovnim okružjima. Proširenje opsega kako bi se obuhvatio širi raspon predmetnih područja, vrsta publikacija i studija mješovitih metoda ili kvalitativnih studija stoga bi moglo poboljšati sveobuhvatnost, bogatstvo i generalizaciju nalaza, nudeći uravnoteženije razumijevanje novih trendova, etičkih razmatranja i praktičnih implikacija za inovacije u politici i pedagogiji.

Nedavni članci često posvećuju znatno manje pažnje etičkim, pravnim i društvenim izazovima koji prate njihovu implementaciju - posebno pitanjima koja se odnose na privatnost, sigurnost podataka, algoritamsku pristranost i pravednu dostupnost. Brojne studije ističu brzo širenje radnih okružja za učenje, praćenje i angažman (npr. Al-Emran i sur., 2023; Almusawi, Durugbo i Bugawa, 2021b; Chu, Garcia i Rani, 2023), kao i njihov pedagoški potencijal u disciplinama, od tjelesnoga odgoja (Lindberg i sur., 2016) do podrške za posebne potrebe (Cheng i Lai, 2020) i STEM okružja za učenje (Fields i sur., 2018). Međutim, znanstvenici tvrde da ubrzano širenje takvih tehnologija može pojačati rizike povezane s izdvajanjem osobnih podataka, biometrijskim nadzorom i nejednakim pristupom ako se te zabrinutosti ne riješe (Borthwick i sur., 2015; Cahyanto i sur., 2023; Picard, 2009). Čak i izvan obrazovnih konteksta, pregledi nosivih zdravstvenih i nadzornih sustava naglašavaju dugogodišnju zabrinutost zbog rukovanja osjetljivim podatcima i pristanka korisnika (Baig, Gholamhosseini i Connolly, 2013; Greiwe i Nyenhuis, 2020; Loncar-Turukalo i sur., 2019), no ta se literatura rijetko integrira u obrazovne analize. Proširenje budućih pregleda kako bi se uključilo sustavno razmatranje etičkih i pravnih okvira stoga bi ponudilo uravnoteženije i kontekstualiziranije razumijevanje nosivih tehnologija u okružjima za učenje te bi podržalo razvoj informiranih smjernica, protokola zaštite i preporuka za odgovornu provedbu (Almusawi, Durugbo i Bugawa, 2021a; Ferreira i sur., 2021; Vijayan i sur., 2021).