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Review article

Identification and evaluation of educational technology trends from 2004 to 2022: Evidence based on computers in human behavior and horizon report

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ABSTRACT

The increasing influence of technology on education has attracted considerable attention. This study aims to determine the current status and development trends of educational technologies. At first, we used COOC, HistCite, and VOSviewer to systematically review 1562 educational articles published in *Computers in Human Behavior* (*CHB*) from 2004 to 2022. Based on bibliometrics, this study identified publication trends, research forces, collaboration, key articles, and research themes. Then, we visualized the technologies predicted by 30 Horizon Reports and combined them with *CHB* educational research to evaluate the accuracy of the identified trends. The results revealed an immediate influence of AI technology, extended reality and digital resources on education, a moderate influence of educational tools and games, and a delayed influence of data management and maker technology. In addition, human psychology and behavior in technological environment may be important themes in the future. In conclusion, this study not only proposes a comparative analysis of leading reports and representative literature, but also provides guidance for future research and development in educational technology.

1. Introduction

With the advent of the information society, the significance of technology in human educational behavior has become increasingly prominent. Technology-supported education emphasizes an information-based teaching environment and an autonomous, cooperative, and inquiry-based learning atmosphere, which are conducive to creating a new learning society and fostering students' innovative spirit and practical skills [1,2]. However, educational technologies are constantly updated and iterated, accelerating changes in learning and teaching styles and placing higher demands on teachers' and students' abilities. Therefore, understanding the trends in educational technology is crucial. First, it contributes to scientific policy-making in education and enables schools to better adapt to the changing technological environment [3]. Second, the development of educational technology can support the transformation of flexible and personalized learning approaches to improve learning effectiveness [4]. Third, teacher roles in technological environment shift from knowledge transmitters to learners, leaders, collaborators, and designers [5]. Finally, the development of educational technology can facilitate the reconstruction and upgrading of the teaching environments to be more interactive and innovative [6]. In

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conclusion, the development of educational technology has implications for innovation in educational theory and practice.

The Horizon Report is a global vane for educational technology documenting the technologies applied in contemporary education, predicting those of the future, and describing various emerging technologies and practices [7]. Since 2004, The New Media Consortium (www.NMC.org) and the EDUCAUSE Learning Initiative (www.educause.edu) have invited numerous experts and scholars worldwide each year (in late 2017, the U.S. New Media Consortium announced bankruptcy). Using Wiki Space as a research platform, they followed a rigorous research path using Delphi qualitative analysis to predict the impact of emerging technologies on global education. Over the first 16 years, the Horizon Report predicted six technology trends through three time-to-adoption horizons: short term (one year or less), midterm (2–3 years), and long term (4–5 years). The purpose is to provide information for decision makers and help learners, teachers, and leaders reflect deeply about the educational technology choices they make and their reasons [8,9]. Since 2020, the time-to-adoption horizon has been omitted from the report [10]. However, the selection of technologies in the Horizon Report is based on their assumed prevalence in research and educational practice rather than specific evidence-based instructional benefits [11]. Therefore, the technologies in the Horizon Report may impact education but are not necessarily the best learning tools verified by research and practice.

However, verifying the development trends of educational technology and guiding the reasonable application of technology in education remain challenging. In educational practice, educators have different perspectives on educational technology and its role and have developed different philosophical views of technology [12,13]. For example, instrumentalism of technology believes that technology is a neutral means of achieving an end, without a distinction between good and bad. It is dominated by humans that technology triggers various outcomes [14,15]. In contrast to technology neutrality, the axiology of technology includes social constructionism and determinism. Social constructionism asserts that technological development depends on the specific social context. Technological change is inevitable in rapidly developing societies [16]. Furthermore, technological utopianism in technological determinism believes that technology can solve problems in education and is positive about the educational value and developmental prospects of technology [17,18], whereas technological dystopianism holds that the development of technology will inevitably bring trouble and disaster to education [19,20]. Driven by these perceptions, some educators are neutral about the technology trends predicted by experts, some are receptive, and others develop negative feelings, such as skepticism and rejection. The key to escaping this dilemma lies in evidence-based support for empirical research and educational practices.

A representative journal analysis can reveal trends and directions of research and practice in the field [21], and is an important method for verifying the prediction of educational technology trends. For example, Inglis and Foster [22] analyzed all articles published since the inception of Educational Studies in Mathematics and the Journal for Research in Mathematics Education to explore changes and developments in mathematics education over a 50-year period. Chatzopoulos and Koidou [23] systematically reviewed the impact of periodontitis-sensitive genotypes and clinical outcomes of periodontal regeneration on the basis of the *Journal of Periodontology*, *Journal of Clinical Periodontology*, and *Journal of Periodontal Research*. Similarly, Cheng, Huang [24]selected five journals in education to investigate research trends and characteristics of educational technology from 2010 to 2019. Bardakci, Soylu [25] conducted a trend study based on 1690 articles published in six educational technology journals. Chen, Zou [21] published a structural topic modeling analysis of 3963 articles in Computers & Education and detected latent topics and trends in educational technologies between 1976 and 2018. We systematically reviewed educational research on *Computers in Human Behavior* (*CHB*) to identify research forces, themes, and trends in educational technology. This study focuses on educational research publications on the *CHB* for several reasons. First, *CHB* is the only journal that discusses human-computer interaction from a psychological perspective and significantly contributes to research on educational technology. Second, *CHB* involves various educational practices and training using computers, as well as explores the impact of computers on phenomena, such as human development, learning, cognition, personality, and interaction. Additionally, *CHB*'s impact on human-computer interaction research has increased annually. By 2023, the impact factor of the *CHB* will reach 9.9 [26].

This study focused on exploring the current status and trends of educational technology. Previous studies usually used content analysis or visualization analysis to demonstrate the structure and themes of educational technology research [24,27]. Mostly, educational technology trends were revealed by comparing keyword frequencies [25,28,29]. In addition, some studies have described the technologies most likely to be adopted in the near future [30,31]. However, few studies have verified the predicted trends of educational technology. There is a lack of systematic evaluation of the authentic influence of technology on education. Therefore, this study used bibliometric analysis to review 1562 educational articles from the *CHB*, and systematically presented the current status of educational research in *CHB*. Then, we evaluated the accuracy of the technology predictions in 30 Horizon Reports with reference to *CHB* educational research. Based on these analyses, this study not only presents the research dynamics and frontiers of educational technology, but also reveals the trends and their influence. This provides a reference for future educational research and practice. Specifically, we proposed the following two research questions.

Research Question 1. What are the results of the *CHB* bibliometric analysis (including publication dynamics, research forces, collaboration, key articles, and research themes)?

Research Question 2. What are the educational technology trends with reference to *CHB* educational publications and the predictions in the Horizon Reports?

2. Methodology

This study used a series of analyses to achieve the proposed objectives. To identify the current status of *CHB* educational technology research, we first collected *CHB* publications between 2004 and 2022. Then, we screened out educational articles and conducted data preprocessing. Finally, we analyzed the bibliometric characteristics of *CHB* educational technology research. Similarly, we first collected all the Horizon reports and classified the key technologies in them to reveal educational technology trends. Then, we coded *CHB* educational articles based on the key technology clusters. Finally, we presented technology trends in *CHB* education research through weighted calculations and Mann-Kendall (M − K) trend test, and compared them with the technology predictions of the Horizon Reports. Overall, the data collection and analysis for this study can be divided into four sub-processes: (1) data collection and pre-processing, (2) bibliometric analysis, (3) identification and classification of key technologies, and (4) analysis of publications and the Horizon Reports. These sub-processes are elaborated in the following four sub-sections.

2.1. Data collection and preprocessing

The *CHB* literature data for this study were obtained from the Web of Science (WoS) core collection, retrieved on July 7, 2023. Because WoS has fully included these data. For the search, "Computers in Human Behavior" was used as the publication title. To understand the development trends of educational technologies affecting human behavior through *CHB* publications, Horizon Reports from 2004 to 2022 were selected as the basis for technology classification. A total of 6813 articles published by the *CHB* from 2004 to 2022 were collected following PRISMA guidelines (see Fig. 1). Then, we screened articles using the following review criteria, which called for excluded studies to be non-educational, research questions unrelated to education, and hardly related to technology. After manual screening, 1562 eligible articles were obtained. To ensure authenticity, four researchers were trained to undertake the selection process in pairs using a protocol.

Data preprocessing guarantees high-quality data mining results. Data preprocessing in this study included six steps. First, all records from the WoS database were exported as plain text files. Second, the key elements of each article were extracted using COOC (e.g., year of publication, author, institution, country, keywords, abstract, and so on) and then saved as an Excel file. Third, articles in the field of education were manually screened. Fourth, additional elements, particularly author keywords, were added. Finally, unimportant terms were screened and excluded on the basis of their frequencies. Sixth, the format and expression of each element were unified. Seventh, terms were extracted from titles, abstracts, keywords and converted to lowercase, and stop words, punctuation, and numbers were removed.

2.2. Bibliometric analysis

First, VOSviewer was used to descriptively analyze the publications, and the number of publications, authors, countries, institutions, cited literature, and author keywords were counted. Second, based on the statistical data, COOC was employed to draw a figure of publication dynamics, and then the "illustration" function built in Word was used to beautify the figure. Third, the plain text files exported from WoS were analyzed through HistCite to identify key articles in *CHB*. The information from the 10 articles with the highest global citation score (GCS) was counted. Using the local citation score (LCS), a co-citation map of 50 cited studies was drawn. Fourth, to analyze the cooperation and key themes, VOSviewer was used to create cooperation networks of countries, institutions, and

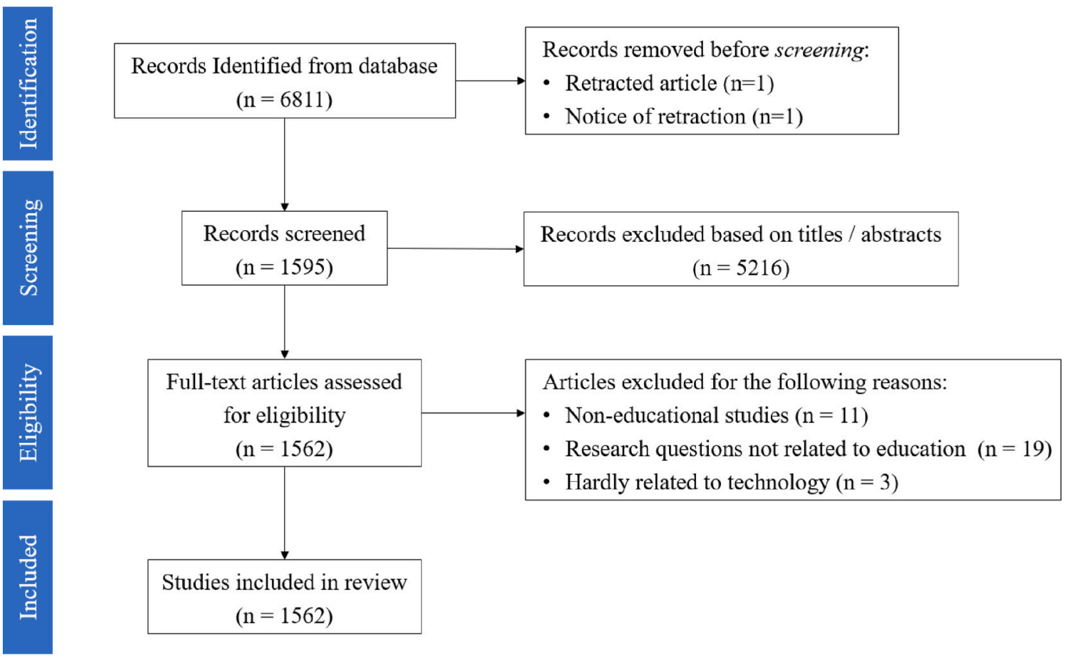


Fig. 1. Flowchart of the data collection.

authors, as well as a clustering map of keywords. The frequency of the maps was set to countries with more than nine articles, institutions with more than 11 articles, authors with more than seven articles, and author keywords with more than nine occurrences.

2.3. Identification and classification of key technologies

According to the time-to-adoption horizons (short-, mid-, and long-term) of the 30 Horizon Reports from 2004 to 2022, the six technologies predicted in each report were recorded and represented visually using Excel. The technologies in all reports were classified and then coded following Dubé and Wen [11], Martin, Diaz [32], Prendes Espinosa and Cerdán Cartagena [33]. Similar technologies were divided into clusters for subsequent bibliometric analyses. There are seven clusters: educational tools, artificial intelligence (AI) technology, data management, extended reality, maker technology, games, and digital resources.

2.4. Analysis of publications and Horizon Reports

Using newly created clusters, the evolutionary trends of educational technology in *CHB* from 2004 to 2022 were analyzed and discussed. First, on the basis of the extracted terms, the articles for each year were coded and grouped into clusters. Second, figures were drawn in Word to analyze the development trends in educational technology on the basis of statistical data. Third, a weighting factor (WF) was adopted to account for annual changes in publications each year [32]. The WF was calculated by dividing the mean number of articles published in the *CHB* from 2004 to 2022 by the number of articles each year. Fourth, the M − K trend test was used to explore technology trends and compare the trends predicted by the Horizon Reports to the weighting factor.

The equation of WF is shown below.

$$WF_i = \frac{\overline{P}}{P_i} = \frac{\frac{1}{N}\sum_{i=2004}^{2022} P_i}{P_i}$$

P = mean number of articles published in *CHB* from 2004 to 2022
P_i = number of articles in year i
$i = \{2004, 2005 \ldots, 2022\}$
N = total number of years

3. Results

3.1. Publications analysis

3.1.1. Publications dynamics

Statistics for *CHB* cases from 2004 to 2022 are shown in Table 1. The samples included 1562 articles, 3856 authors from 1211 institutions in 77 countries, cited 59726 references, with 4069 author keywords.

Fig. 2 shows the number and trend of CHB's publications from 2004 to 2022. According to the curve depicted in Fig. 2, the increase in educational publications in the *CHB* can be divided into three stages: stable development, rapid growth, and quality improvement. During the stable development period (2004–2011), the number of *CHB* publications steadily increased, with an annual average of approximately 47. During the rapid growth stage (2012–2016), the number of publications exponentially increased. Within five years, the total number of publications reached 2520, with an average of 667 each year, 14 times more than in the previous stage. During the quality improvement stage (2017–2022), the number of publications in *CHB* decreased significantly, with an annual average of approximately 85 and a total of 515.

3.1.2. Country, institution, and author analysis

Productive countries and cooperation. The ten most productive countries and regions were sorted and recorded, as exhibited in Table 2. Among the 77 countries and regions, the United States of America had the most publications with 248 more publications than the Netherlands. Four of the ten most productive countries and regions are located in Europe, three in Asia, two in North America, and one in Oceania. To further understand the country cooperation, a cooperation network of 33 countries and regions (publications ≥10) was produced, as shown in Fig. 3. The size of the labels and lines represents the number of publications and the intensity of

Table 1
Statistics of the *CHB*.

Criteria	Quantity
Publications	1562
Authors	3856
Countries	77
Institutions	1211
Cited references	59726
Author keywords	4069

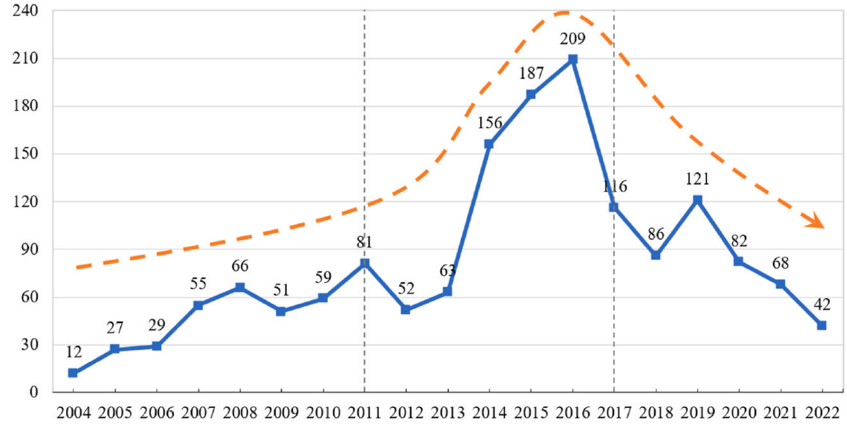


Fig. 2. Number of publications.

Table 2
Most productive countries/regions.

Rank	Country/region	Publication	Citation	Average citation/publication
1	USA	412	16429	39.88
2	The Netherlands	173	6034	34.88
3	Taiwan	154	5227	33.94
4	Germany	153	4680	30.59
5	Spain	142	5849	41.19
6	Peoples R China	97	2761	28.46
7	England	74	3168	42.81
8	Australia	67	1963	29.30
9	Turkey	62	2283	36.82
10	Canada	59	2661	45.10

cooperation, and the colors represent the subnetworks of cooperation. The results demonstrate that countries in Europe, North America, and Asia cooperate closely, whereas African and South American countries do not.

Productive institutions and cooperation. In Table 3, the institutions with more than 40 publications are National Taiwan Normal University in Taiwan, China, and Open Universiteit Nederland in the Netherlands. In addition, The Open University in England has the highest average citation, reflecting its high research level. Fig. 4 presents the cooperation network of the 26 institutions (publications ≥12, see co-countries network for the meaning of labels, lines, and colors). Among the 10 most productive institutions, the Open University of the Netherlands, Universiteit Utrecht, University of Twente, The Open University, Knowledge Media Resource Center, Erasmus University Rotterdam, and University of Tubingen cooperate closely. Cooperation was observed between National Normal

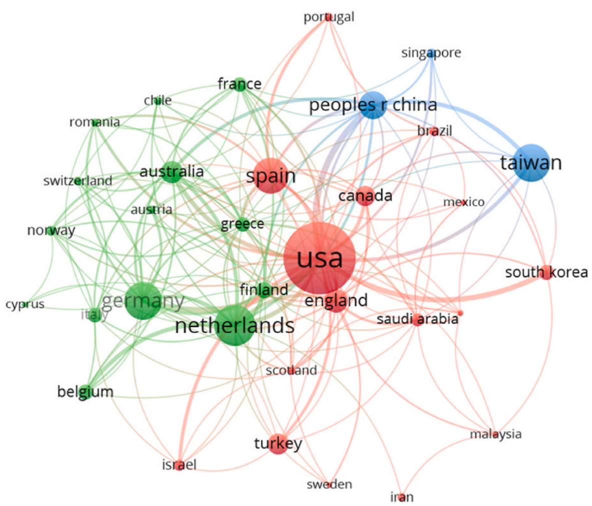


Fig. 3. Map of co-countries network.

Table 3
Most productive institutions.

Rank	Institution	Publication	Citation	Average citation/publication
1	National Taiwan Normal University, Taiwan, Peoples R China	45	1029	22.87
2	Open University of the Netherlands, Netherlands	44	2040	46.36
3	Universiteit Utrecht, Netherlands	37	1538	41.57
4	University of Twente, Netherlands	34	1039	30.56
5	The Open University, England	21	1037	49.38
6	Knowledge Media Resource Center, Germany	21	701	33.38
7	Erasmus University Rotterdam, Netherlands	20	701	35.05
8	University of Salamanca, Spain	19	839	44.16
9	National Taiwan University of Science and Technology, Taiwan, Peoples R China	19	509	26.79
10	University of Tubingen, Germany	18	649	36.06

University and National Taiwan University of Science and Technology. The University of Salamanca did not cooperate with any of the other 9 institutions.

Productive authors and cooperation. The 10 most productive authors, as well as the number of educational articles they published in the *CHB*, citations, and their percentages, are presented in Table 4. Among these, Kirschner was the most productive author, with 22 articles. Rienties ranked 10th with eight articles. A difference of 14 articles was found in the number of publications between the 1st and 10th ranks. The authors with the largest differences in the number of publications were the first and second authors, and Kirschner published nine more articles than Mayer. Moreover, Kirschner's average citation rate is much higher than that of the other authors, indicating that his studies are generally at a high level. Fig. 5 shows the cooperation of 18 authors (publications ≥8, see co-countries network for the meaning of labels, lines, and colors). Kirschner, Paas, Jarvela, Clarebout, Van Merrienboer, and other authors constitute the largest cooperation sub-network, whereas Mayer, Jou, Rey, Tsai, and Rienties are independent of the network.

3.1.3. Citation analysis

The 10 most-cited articles (i.e., global citation score, abbreviated as GCS) published in the *CHB* are shown in Table 5. Tokunaga [34] ranked 1st with 1247 citations. Kirschner and Karpinski [35] ranked 2nd, with 748 citations. Kirschner was the most productive author in this study. This indicates that Kirschner made significant contributions to *CHB* educational research and had a significant influence on the research field of computer-supported learning. The articles with the largest differences in citations were the first and second. Tokunaga [34] has 499 more citations than Kirschner and Karpinski [35].

In this study, 50 articles with the highest local citation score (LCS) were selected, and a map of the co-cited articles was created, as shown in Fig. 6. Arabic numerals represent the number of the literature. The size of the circles represents local citations and the direction of the arrows represents one article citing another. Article 22 was published earlier and cited more often. Therefore, it may be a seminal article [44]. Article 286 was cited five times, with the most citations, indicating that it is an important article in the *CHB* [35]. In addition, Articles 30, 60, and 161 strongly influenced the development of *CHB* [45–47].

3.1.4. Theme analysis

The keywords in the *CHB* studies were statistically analyzed, and the 20 most frequent keywords were obtained, as shown in Table 6. Collaborative learning, learning, e-learning, learning analytics, higher education, cognitive load, multimedia learning, self-managed learning, social media, and motivation are popular in *CHB* educational research. Additionally, topics, such as Facebook, mobile learning, computer-supported collaborative learning, game-based learning, self-efficacy, learning performance, gamification,

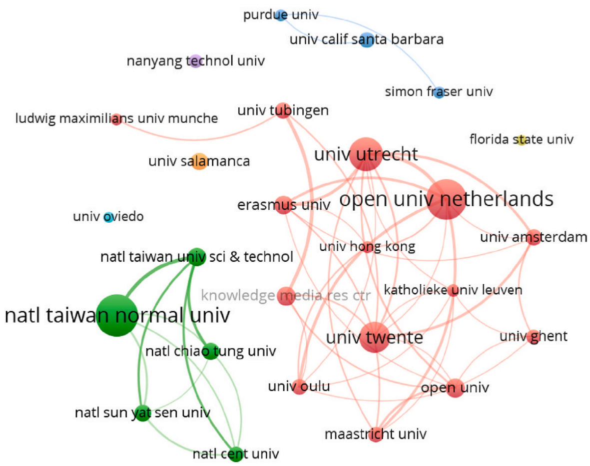


Fig. 4. Map of co-institutions network.

Table 4
Most productive authors.

Rank	Author	Country/region	Publication	Citation	Average citation/publication
1	Kirschner, Paul A.	Netherlands	22	1676	76.18
2	Mayer, Richard E.	USA	13	429	33.00
3	Paas, Fred	The Netherlands	10	392	39.20
4	Jou, Min	Taiwan	10	211	21.10
5	Rey, Guenter Daniel	Germany	10	109	10.90
6	Tsai, Chin-Chung	Taiwan	9	252	28.00
7	Jarvela, Sanna	Finland	9	237	26.33
8	Clarebout, Geraldine	The Netherlands	9	236	26.22
9	Van Merrienboer, Jeroen J. G.	The Netherlands	9	168	18.67
10	Rienties, Bart	England	8	628	78.50

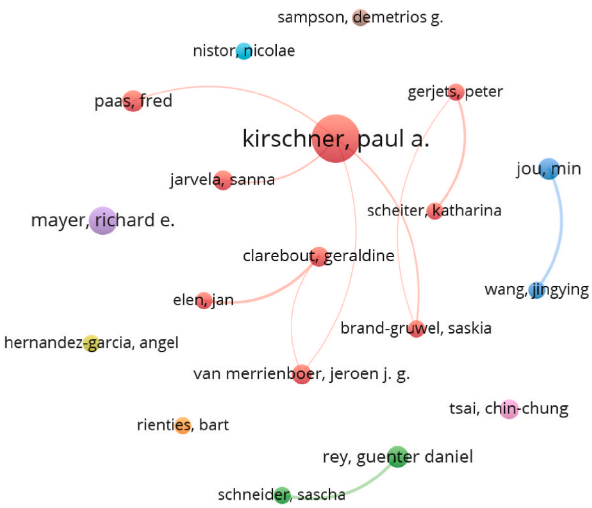


Fig. 5. Map of co-authors network.

Table 5
Most cited articles.

Rank	Number	Reference	GCS	LCS	LCR	CR
1	249	Tokunaga [34]	1247	13	0	80
2	286	Kirschner and Karpinski [35]	748	31	0	55
3	843	Hamari, Shernoff [36]	697	5	5	101
4	1071	Sailer, Hense [37]	639	6	0	80
5	635	Lye and Koh [38]	558	13	0	89
6	906	Samaha and Hawi [39]	554	9	4	51
7	323	Kim, Sohn [40]	503	2	0	57
8	481	Tess [41]	487	7	2	72
9	1058	Wu and Chen [42]	454	2	2	49
10	433	Slonje, Smith [43]	431	4	2	64

computer-mediated communication, online learning, and instructional design were extensively studied.

To explore the research themes of *CHB*, co-occurrence analysis was conducted on the keywords using VOSviewer, and a map of keyword clustering was obtained, as shown in Fig. 7. The network contains 79 items (frequencies ≥10), 506 links, and 4 clusters. The size of the circles and lines represents the number of publications and occurrences, and the colors represent the research themes. Four popular topics were identified through analysis and summary: technology-supported student development, technology-supported learning analysis, psychology and behavior in the technological environment, and the integration of technology and learning.

Technology-supported student development (red). The first research theme included author keywords, such as cognitive load (45), self-efficacy (25), academic performance (24), instructional design (21), problem solving (20), gender (19), assessment (16), computational thinking (15), personality (13), and self-regulation (12).

Technology-supported learning analytics (green). The second research theme was represented by author keywords, such as e-learning (61), learning analytics (51), higher-education (47), motivation (40), game-based learning (28), online learning (21), social network analysis (16), performance (12), and learning outcomes (10).

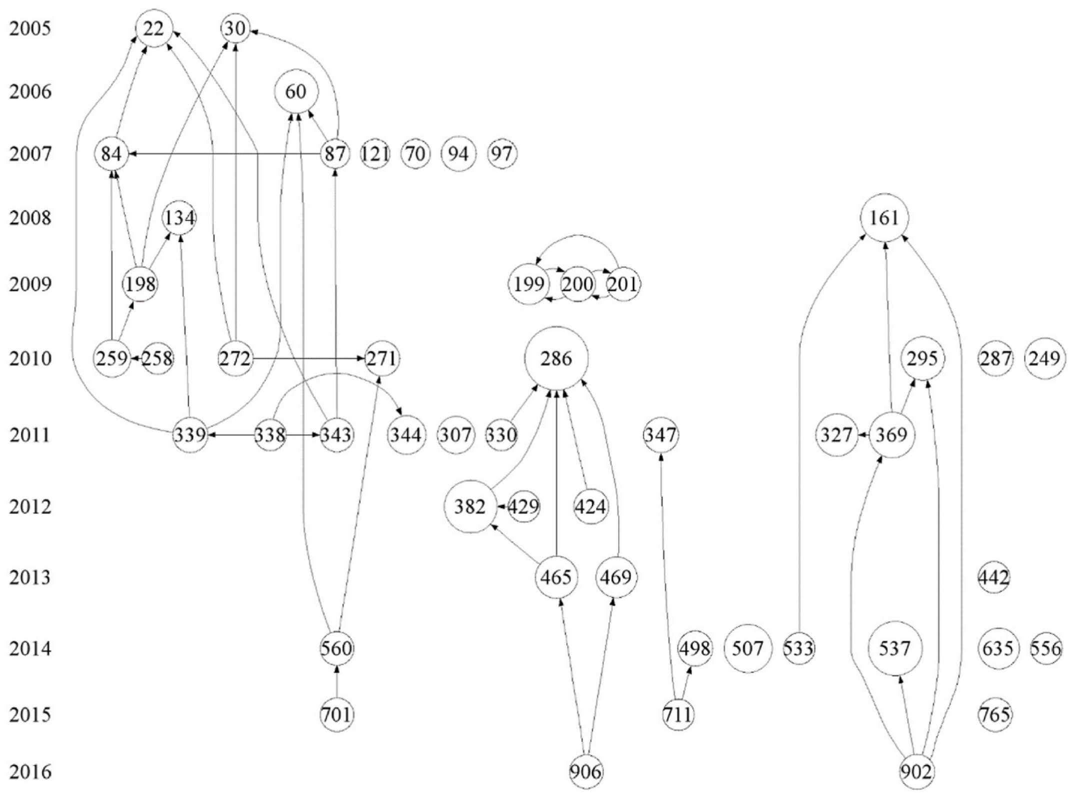


Fig. 6. Map of co-cited articles.

Table 6
High-frequency keywords.

Rank	Keyword	Frequency	Rank	Keyword	Frequency
1	Collaborative learning	69	11	Facebook	37
2	Learning	66	12	Mobile learning	30
3	E-learning	61	13	Computer-supported collaborative learning	28
4	Learning analytics	51	14	Game-based learning	28
5	Higher education	47	15	Self-efficacy	25
6	Cognitive load	45	16	Academic performance	24
7	Multimedia learning	43	17	Gamification	23
8	Self-regulated learning	41	18	Computer-mediated communication	22
9	Social media	41	19	Online learning	21
10	Motivation	40	20	Instructional design	21

Psychology and behavior in technological environment (blue). The author keywords for the third research theme were learning (66), social media (41), Facebook (37), internet (18), children (17), metacognition (15), cyberbullying (15), multimedia (13), anxiety (12), and internet addiction (12).

Integration of technology and learning (yellow). The author keywords of the fourth research theme included collaborative learning (69), self-regulated learning (41), mobile learning (30), computer-supported collaborative learning (28), computer-mediated communication (22), secondary education (19), collaboration (15), intelligent tutoring systems (15), feedback (14), and augmented reality (13).

3.2. *Educational technology trends*

Fig. 8 shows the technology trends predicted by the 30 Horizon Reports from 2004 to 2022. Reports from 2004 to 2019 show that the two technologies were adopted in the short, mid, and long terms. From 2020, predictions on the speed of technology adoption will no longer be the focus of Horizon Reports. In Fig. 8, different colored borders and fills are used to distinguish between the different Horizon Reports and technology clusters. Specifically, yellow, purple, dark blue, orange, green, light red, and light blue represent educational tools, AI technology, data management, extended reality, marker technology, games, and digital resources, respectively.

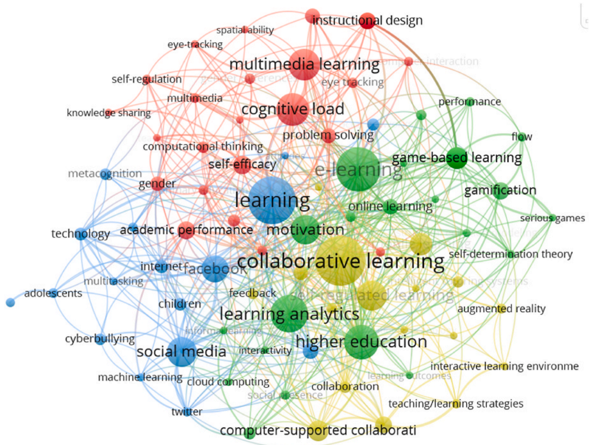


Fig. 7. Map of keywords clustering.

The bottom of Fig. 8 shows each technology's occurrences and percentage.

On the basis of the work in the previous stage, the educational technology trends in the *CHB* were analyzed. Table 7 exhibits the number of educational articles available on *CHB* from 2004 to 2022 and their weighting factors. Using the weighting formula of Martin, Diaz [32], the weighted number, trend, and significance of publications for each technology cluster from 2004 to 2022 were obtained, as shown in Fig. 9. In CHB educational research from 2004 to 2022, there was an extremely significant downward trend in educational tools, a statistically significant upward trend in AI technology, a significant upward trend in data management and extended reality, an extremely significant upward trend in maker technology and games, and no statistically significant trend in digital resources. Similarly, Figs. 10–16 display the developmental trends and contributions of each technology.

3.2.1. *Educational tools*

Educational tools refer to technical tools designed for education [33], such as mobile devices, networks, applications, and multimedia. In the Horizon Reports from 2004 to 2022, educational tools appeared 59 times, accounting for the largest proportion of overall predictions (33 %). Specifically, mobile devices and networks, applications, and multimedia appeared 35 times, 22 times, and 3 times, respectively (mobile devices and applications recurred once). In *CHB* educational research from 2004 to 2022, there was a significant downward trend in mobile devices and networks, an extremely significant downward trend in applications, and no statistically significant trend in multimedia (see Fig. 10).

The 2004 Horizon Report predicted that multimedia would be adopted within one year. Since 2009, the Horizon Report has no longer predicted multimedia separately, which is fully consistent with the *CHB*'s bibliometric results. Application predictions were first reported in the 2008 Horizon Report [48]. In 2005, the *CHB* had already seen a spike in relevant publications, suggesting that the *CHB*'s educational research on applications predated Horizon Reports' predictions. Similarly, the *CHB*'s educational research on mobile devices and networks was a year ahead of Horizon Reports. After a lull period, the number of publications suddenly increased by 2021.

3.2.2. *AI technology*

AI technology refers to the ability of computers to simulate, extend, and expand human intelligence. Applications in education mainly include three key technologies: human-computer interaction, learning analytics, and social networks. In the Horizon Reports from 2004 to 2022, AI technology appeared 49 times, accounting for the second largest proportion (27 %). Specifically, human-computer interaction appeared 22 times, learning analytics appeared 20 times, and social networking appeared 7 times. In *CHB* educational research from 2004 to 2022, there was a significant upward trend in social network, and no statistically significant trend in human-computer interaction and learning analytics (see Fig. 11).

CHB publications on human-computer interaction were consistently the lowest among the three technologies, contrary to their frequency in Horizon Reports. However, this situation is not untraceable in Horizon Reports. From 2004 to 2022, the focus of human-computer interaction will shift from multimodal interfaces to natural user interfaces and from context-aware computing and gesture-based computing to affective computing and virtual assistants. However, the predictions of human-computer interaction are in the mid and long terms. The prediction of learning analytics first appeared in the long term in the 2011 Horizon Report [49]. In 2004, the *CHB* published several articles on learning analytics. In terms of learning analytics, *CHB* studies were clearly ahead of the Horizon Reports. Fig. 11 shows that the trend in publications on learning analytics fluctuates significantly. In Horizon Reports, learning analytics jumped repeatedly between short-term, mid-term, and long-term predictions. Regarding social networks, the *CHB* publications showed an inverted U-shaped trend, which is consistent with the predicted trend of the Horizon Reports. In 2004–2009, Horizon Reports' predictions for social networks rapidly shifted from long term to short term [50], and then to long term. After 2009, social networks disappeared from Horizon Reports.

Horizon Report	Emerging Technologies & Practices					
2022 (Data and Analytics)	Data Management and Governance	Unifying Data Sources	Modern Data Architecture	Data Literacy Training	DEI for Data and Analytics	Assessing and Improving Institutional Data and Analytics Capabilities
2022 (Teaching and Learning)	AI for Learning Analytics	AI for Learning Tools	Hybrid Learning Spaces	Mainstreaming Hybrid/Remote Learning Modes	Microcredentials	Professional Development for Hybrid/Remote Teaching
2021 (Information Security)	Cloud Vendor Management	Endpoint Detection and Response	Multifactor Authentication/Single Sign-On	Preserving Data Authenticity/Integrity	Research Security	Student Data Privacy and Governance
2021 (Teaching and Learning)	Artificial Intelligence	Blended and Hybrid Course Models	Learning Analytics	Microcredentialing	Open Educational Resources	Quality Online Learning
2020 (Teaching and Learning)	Adaptive Learning Technologies	AI/Machine Learning Education Applications	Analytics for Student Success	Elevation of Instructional Design, Learning Engineering, and UX Design	Open Educational Resources	XR (AR, VR, MR, Haptic) Technologies
Horizon Report	**One Year or Less**		**Two to Three Years**		**Four to Five Years**	
2019 (Higher Education)	Mobile Learning	Analytics Technologies	Mixed Reality	Artificial Intelligence	Blockchain	Virtual Assistants
2018 (Higher Education)	Analytics Technologies	Makerspaces	Adaptive Learning Technologies	Artificial Intelligence	Mixed Reality	Robotics
2017 (Higher Education)	Adaptive Learning Technologies	Mobile Learning	The Internet of Things	The Next-Generation LMS	Artificial Intelligence	Natural User Interfaces
2017 (K-12)	Makerspaces	Robotics	Analytics Technologies	Virtual Reality	Artificial Intelligence	The Internet of Things
2016 (Higher Education)	Bring Your Own Device (BYOD)	Learning Analytics and Adaptive Learning	Augmented and Virtual Reality	Makerspaces	Affective Computing	Robotics
2016 (K-12)	Makerspaces	Online Learning	Robotics	Virtual Reality	Artificial Intelligence	Wearable Technology
2015 (Higher Education)	Bring Your Own Device (BYOD)	Flipped Classroom	Makerspaces	Wearable Technology	Adaptive Learning Technologies	The Internet of Things
2015 (K-12)	Bring Your Own Device (BYOD)	Makerspaces	3D Printing	Adaptive Learning Technologies	Digital Badges	Wearable Technology
2014 (Higher Education)	Flipped Classroom	Learning Analytics	3D Printing	Games and Gamification	Quantified Self	Virtual Assistants
2014 (K-12)	BYOD	Cloud Computing	Games and Gamification	Learning Analytics	The Internet of Things	Wearable Technology
2013 (Higher Education)	Massively Open Online Courses	Tablet Computing	Games and Gamification	Learning Analytics	3D Printing	Wearable Technology
2013 (K-12)	Cloud Computing	Mobile Learning	Learning Analytics	Open Content	3D Printing	Virtual and Remote Laboratories
2012 (Higher Education)	Mobile Apps	Tablet Computing	Game-Based Learning	Learning Analytics	Gesture-Based Computing	Internet of Things
2012 (K-12)	Mobile Devices & Apps	Tablet Computing	Game-Based Learning	Personal Learning Environments	Augmented Reality	Natural User Interfaces
2011 (K-12)	Cloud Computing	Mobiles	Game-Based Learning	Open Content	Learning Analytics	Personal Learning Environments
2011	Electronic Books	Mobiles	Augmented Reality	Game-Based Learning	Gesture-Based Computing	Learning Analytics
2010 (K-12)	Cloud Computing	Collaborative Environments	Game-Based Learning	Mobiles	Augmented Reality	Flexible Displays
2010	Mobile Computing	Open Content	Electronic Books	Simple Augmented Reality	Gesture-Based Computing	Visual Data Analysis
2009 (K-12)	Collaborative Environments	Online Communication Tools	Mobiles	Cloud Computing	Smart Objects	The Personal Web
2009	Mobiles	Cloud Computing	Geo-everything	The Personal Web	Semantic-aware Applications	Smart Objects
2008	Grassroots Video	Collaboration Webs	Mobile Broadband	Data Mashups	Collective Intelligence	Social Operating Systems
2007	User-Created Content	Social Networking	Mobile Phones	Virtual Worlds	The New Scholarship and Emerging Forms of Publication	Massively Multiplayer Educational Gaming
2006	Social Computing	Personal Broadcasting	The Phones in Their Pockets	Educational Gaming	Augmented Reality and Enhanced Visualization	Context-Aware Environments and Devices
2005	Extended Learning	Ubiquitous Wireless	Intelligent Searching	Educational Gaming	Social Networks & Knowledge Webs	Context-Aware Computing/Augmented Reality
2004	Learning Objects	Scalable Vector Graphics (SVG)	Rapid Prototyping	Multimodal Interfaces	Context Aware Computing	Knowledge Webs
Educational Tools (59 times, 33%)	**AI Technology** (49 times, 27%)	**Data Management** (25 times, 14%)	**Extended Reality** (15 times, 8%)	**Maker Technology** (15 times, 8%)	**Games** (11 times, 6%)	**Digital Resources** (6 times, 3%)

Fig. 8. Important development of technologies according to the Horizon Reports from 2004 to 2022.

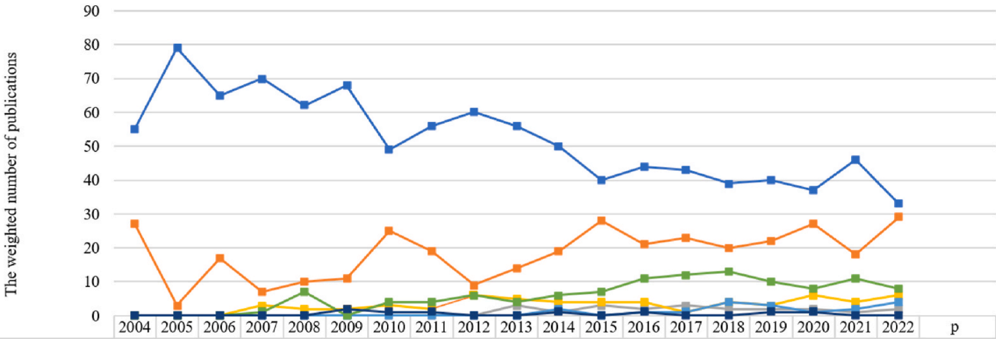
3.2.3. *Data management*

Data management refers to the process of recording, retaining, counting, mining, and generalizing data. In this study, data management specifically includes emerging technologies for data storage, analysis, and processing. In the Horizon Reports from 2004 to 2022, data management appeared 25 times, accounting for the third largest proportion (14 %). Among these, cloud computing appeared 8 times, data security 7 times, the Internet of Things 5 times, and blockchain once. The other four predictions were related to digital capabilities and tool construction. In *CHB* educational research from 2004 to 2022, there was a significant upward trend in data security, and no statistically significant trend in cloud computing, the Internet of Things, and blockchain (see Fig. 12).

Cloud computing, the Internet of Things, and blockchain were first reported in the 2009 Horizon Report, long-term predictions in the 2012 Horizon Report, and long-term predictions in the 2019 Horizon Report. In *CHB* publications, only the Internet of Things met

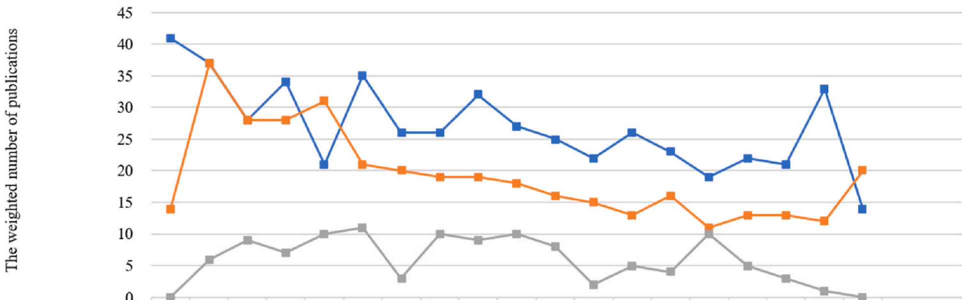
Table 7
Number of educational articles available in *CHB* from 2004 to 2022 and their weighting factor.

Year	Number of papers available	Weighting factor (WFi)	Year	Number of papers available	Weighting factor (WFi)
2004	12	6.850877193	2014	156	0.526990553
2005	27	3.044834308	2015	187	0.439628483
2006	29	2.834845735	2016	209	0.393351801
2007	55	1.494736842	2017	116	0.708711434
2008	66	1.245614035	2018	86	0.955936353
2009	51	1.611971104	2019	121	0.679425837
2010	59	1.393398751	2020	82	1.002567394
2011	81	1.014944769	2021	68	1.208978328
2012	52	1.580971660	2022	42	0.526990553
2013	63	1.304928989			



	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	p
Educational Tools	55	79	65	70	62	68	49	56	60	56	50	40	44	43	39	40	37	46	33	-0.000***
AI Technology	27	3	17	7	10	11	25	19	9	14	19	28	21	23	20	22	27	18	29	0.014*
Data Management	0	0	0	0	0	0	0	0	0	3	1	3	2	3	2	2	2	1	2	0.004**
Extended Reality	0	0	0	3	2	2	3	2	6	5	4	4	4	1	4	3	6	4	6	0.003**
Maker Technology	0	0	0	0	0	0	0	0	0	0	2	0	1	1	4	3	1	2	4	0.000***
Games	0	0	0	1	7	0	4	4	6	4	6	7	11	12	13	10	8	11	8	0.000***
Digital Resources	0	0	0	0	0	2	1	1	0	0	1	0	1	0	0	1	1	0	0	0.708

Fig. 9. Weighted number of educational articles available in *CHB* from 2004 to 2022.
Note: *p < 0.05; **p < 0.01; ***p < 0.001.



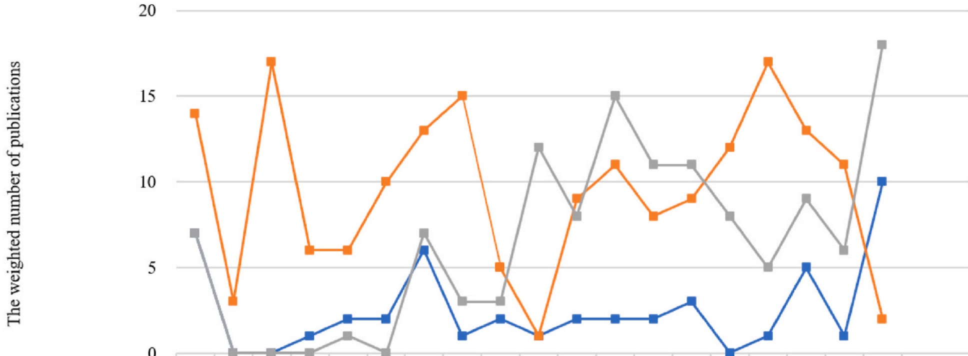
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	p
Mobile Devices and Networks	41	37	28	34	21	35	26	26	32	27	25	22	26	23	19	22	21	33	14	-0.002**
Applications	14	37	28	28	31	21	20	19	19	18	16	15	13	16	11	13	13	12	20	-0.000***
Multimedia	0	6	9	7	10	11	3	10	9	10	8	2	5	4	10	5	3	1	0	-0.121

Fig. 10. Publishing evolution of educational tools from 2004 to 2022 according to *CHB*.
Note: *p < 0.05; **p < 0.01; ***p < 0.001.

the predictions of the Horizon Reports. In addition, cloud computing was published after the Horizon Reports' predictions, and blockchain did not even have any relevant educational articles. The 2021 and 2022 Horizon Report issued special editions regarding "Information Security" and "Data and Analytics" [51,52]. Since 2017, the *CHB* has been concerned about data security in education.

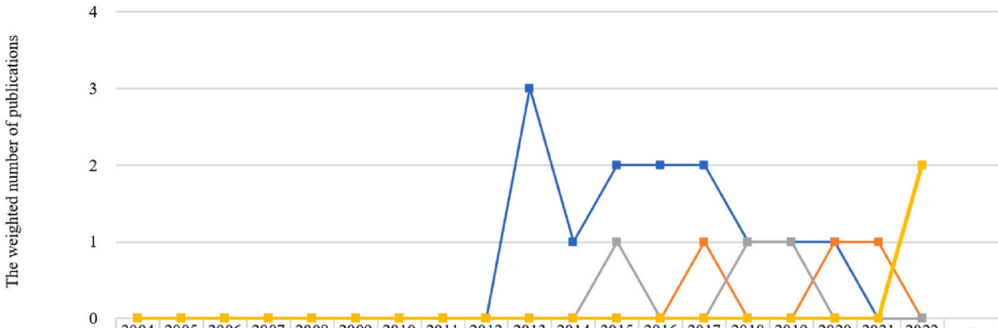
3.2.4. Extended reality

Extended reality refers to combining the real with the virtual, or providing a completely virtual environment, including augmented,



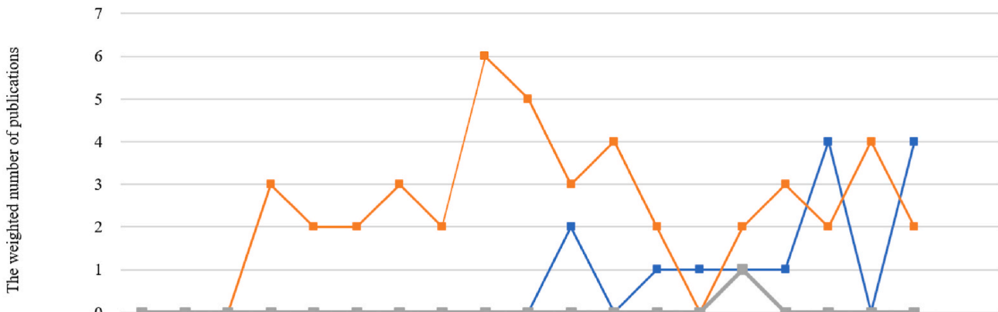
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	p
Human-Computer Interaction	7	0	0	1	2	2	6	1	2	1	2	2	2	3	0	1	5	1	10	0.348
Learning Analytics	14	3	17	6	6	10	13	15	5	1	9	11	8	9	12	17	13	11	2	0.861
Social Network	7	0	0	0	1	0	7	3	3	12	8	15	11	11	8	5	9	6	18	0.005**

Fig. 11. Publishing evolution of AI technology from 2004 to 2022 according to *CHB*.
Note: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.



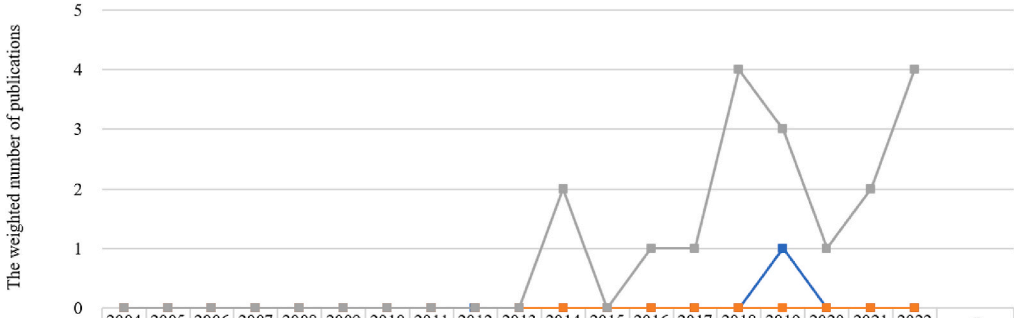
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	p
Cloud Computing	0	0	0	0	0	0	0	0	0	3	1	2	2	2	1	1	1	0	0	0.968
Data Security	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0.039*
Internet of Things	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0.162
Blockchain	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0.121

Fig. 12. Publishing evolution of data management from 2004 to 2022 according to *CHB*.
Note: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.



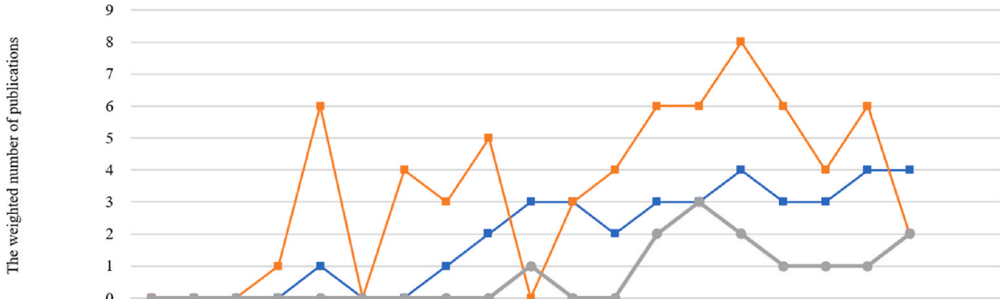
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	p
Augmented Reality	0	0	0	0	0	0	0	0	0	0	2	0	1	1	1	1	4	0	4	0.002**
Virtual Reality	0	0	0	3	2	2	3	2	6	5	3	4	2	0	2	3	2	4	2	0.216
Mixed Reality	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0.411

Fig. 13. Publishing evolution of extended reality from 2004 to 2022 according to *CHB*.
Note: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.



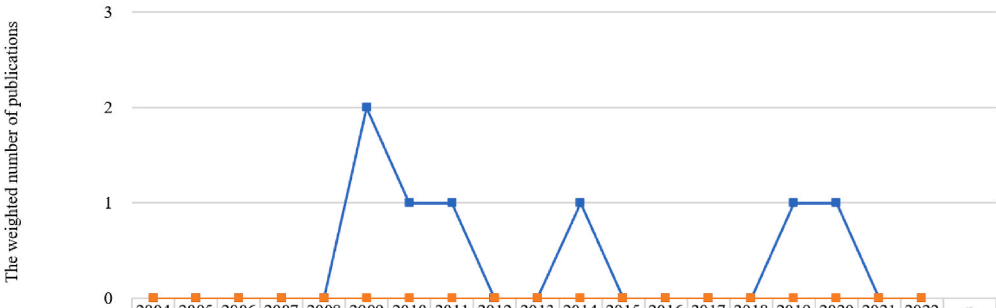
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	p
Makerspaces	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0.315
3D Printing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA
Robotics	0	0	0	0	0	0	0	0	0	0	2	0	1	1	4	3	1	2	4	0.000***

Fig. 14. Publishing evolution of maker technology from 2004 to 2022 according to *CHB*.
Note: *p < 0.05; **p < 0.01; ***p < 0.001; NA = not applicable.



	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	p
Game-based Learning	0	0	0	0	1	0	0	1	2	3	3	2	3	3	4	3	3	4	4	0.000***
Educational Games	0	0	0	1	6	0	4	3	5	0	3	4	6	6	8	6	4	6	2	0.008**
Gamefication	0	0	0	0	0	0	0	0	0	1	0	0	2	3	2	1	1	1	2	0.002**

Fig. 15. Publishing evolution of games from 2004 to 2022 according to *CHB*.
Note: *p < 0.05; **p < 0.01; ***p < 0.001.



	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	p
Dynamic Resources	0	0	0	0	0	2	1	1	0	0	1	0	0	0	0	1	1	0	0	0.862
Static Resources	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA

Fig. 16. Publishing evolution of digital resources from 2004 to 2022 according to *CHB*.
Note: *p < 0.05; **p < 0.01; ***p < 0.001; NA = not applicable.

virtual, and mixed realities. In the Horizon Reports from 2004 to 2022, extended reality appeared 15 times, accounting for the fourth largest proportion of the overall predictions (8 %). Specifically, augmented reality appeared 8 times, virtual reality 5 times, mixed reality 2 times, and extended reality appeared once (augmented reality and virtual reality occurred once). In *CHB* educational research from 2004 to 2022, there was a significant upward trend in augmented reality, and no statistically significant trend in virtual reality and mixed reality (see Fig. 13).

Augmented reality, virtual reality, and mixed reality first appeared in the long-term predictions of the 2005 Horizon Report, midterm predictions in the 2007 Horizon Report, and long-term predictions in the 2018 Horizon Report. In the *CHB*, virtual and mixed realities were published earlier than the predictions of Horizon Reports, whereas augmented reality was published much later.

3.2.5. Maker technology

Creativity is a hands-on, inquiry-based, and experiential learning approach. The emergence of 3D printing, robotics, and makerspaces has had a substantial impact on individual innovation, driving innovation in education and practice [11]. In *CHB* educational research from 2004 to 2022, there was an extremely significant upward trend in robotics, and no statistically significant trend in makerspaces, no articles on 3D printing (see Fig. 14).

In the Horizon Reports from 2004 to 2022, maker technology appeared 15 times, accounting for the fourth largest proportion (9 %). Specifically, makerspaces, 3D printing, and robotics appeared six, five, and four times, respectively. Among them, the makerspaces continued to appear in the Horizon Reports from 2015 to 2022, but only appeared once in the publication of *CHB* in 2019. 3D printing was the earliest technology to appear in the Horizon Reports, and it was never addressed in the publications of the *CHB*. In 2016–2018, robotics repeatedly changed the short-, mid-, and long-term predictions of Horizon Reports. However, it is an earlier and more advanced maker technology in the *CHB* compared to the former two.

3.2.6. Games

The pedagogical purpose of games is to teach and entertain learners by provoking their interest and thinking through play. In the Horizon Reports from 2004 to 2022, games appeared 11 times, accounting for the sixth-largest proportion of overall predictions (6 %). Specifically, game-based learning appeared 5 times, educational games 3 times, and gamification 3 times. In *CHB* educational research from 2004 to 2022, there was an extremely significant upward trend in game-based learning, and a significant upward trend in educational games and gamification (see Fig. 15).

An analysis of Horizon Reports revealed that educational games first appeared in mid-term predictions in 2005 [53]. Not until 2010 was game-based learning mentioned in the Horizon Report's (K-12) midterm predictions [54]. Gamification was reported in the midterm predictions of the 2013 Horizon Report (Higher Education) [55]. According to Fig. 15, the *CHB*'s publication time in educational games was later than the adoption time predicted by Horizon Reports, and game-based learning and gamification were predicted earlier. In conclusion, *CHB* research on games started relatively late, but showed great advancement and high-level research quality in subsequent development.

3.2.7. Digital resources

In this study, digital resources refer to open and shared online resources. In the Horizon Reports from 2004 to 2022, digital resources appeared six times, accounting for the smallest percentage of the overall predictions (3 %). Specifically, the dynamic and static resources appeared 6 and 0 times, respectively. In *CHB* educational research from 2004 to 2022, there was no statistically significant trend in dynamic resources and no articles on static resources (see Fig. 16).

In 2010–2013, dynamic resources appeared in the short- and mid-term predictions of the Horizon Reports. After a period of disappearance, it reappeared in the long-term predictions of the Horizon Report (Teaching and Learning) in 2020 and 2021 [10,56], which is consistent with the publication dynamics of the *CHB*. The earliest *CHB* article on dynamic resources was published in 2009, slightly ahead of the predictions of the Horizon Reports. After a period of zero publications, it regained attention in 2019. As for static resources, they have never been mentioned separately by the Horizon Reports, and *CHB* has never published relevant articles.

4. Discussion

4.1. Discussion of results

4.1.1. Research status

This study conducted a bibliometric analysis of 1562 educational articles published in the *CHB* between 2004 and 2022, including publication trends, research forces, key articles, and research themes. We have reached important conclusions regarding the research and development of educational technology.

First, 2016 was a turning point in educational publications on the *CHB*. From 2004 to 2016, the large-scale application of new technologies in education contributed to the development of educational technology research in the *CHB*. Therefore, the number of educational articles published in the *CHB* grew rapidly during this period, especially from 2012 to 2016. After 2016, the *CHB* placed higher requirements on the quality of scientific research in publications, resulting in a sharp decline in the number of educational articles [57].

Second, compared with Cheng, Huang [24] bibliometric analysis of five educational technology journals from 2010 to 2019, we found that the *CHB* concentrates a significant research force in the field of educational technology. In terms of productive countries, the nine productive countries in this study were in the top 10 of Cheng, Huang [24] except for Germany. Among them, the United States of America is the largest contributor and closely cooperates with other 9 productive countries and regions. In terms of productive institutions, Cheng, Huang [24] and this study demonstrated that institutions in Taiwan, China, and the Netherlands were important research forces, such as National Taiwan Normal University, National Taiwan University of Science and Technology, and The Open University. Currently, cooperation among institutions is largely limited by their geographic locations. Therefore, we expect that the advancement of policies and the development of technology can overcome the spatial and temporal limitations and facilitate cross-regional exchange and cooperation. In terms of productive authors, Chin-Chung Tsai is a co-author of Cheng, Huang [24] and this study, and is a significant contributor to educational technology research. In this study, all the 10 most productive authors formed their own teams, indicating the importance of stable research teams and research directions for authors [58].

Third, *CHB* educational technology articles had an outstanding influence. To date, the citations of the 10 most-cited articles in Cheng, Huang [24] are in the range of 266–7342, and that of *CHB* is 431–1247. In addition, among the 10 most productive authors working on educational technology research in the *CHB*, only one of Kirchner's articles ranked in the top 10, with the highest GCS. This further illustrates that the *CHB* is more concerned with the quality of research than with the contributions of the authors.

Finally, *CHB* provides more comprehensive implications for educational technology research than Bardakci, Soylu [25], who used visualization to identify the research content of six educational technology journals from 2014 to 2018. In terms of high-frequency keywords, collaborative, higher education, and e-learning were the concepts that both studies focused on. Self-efficiency is also a high-frequency keyword in *CHB* educational research and has been the least frequently studied, as shown by Bardakci, Soylu [25]. The results imply that technology-supported learning is gaining increasing attention, especially in higher education [59]. However, current educational technology research lacks attention to human psychology and behavior, aspects of which *CHB* has not been neglected. In terms of research themes, Bardakci, Soylu [25] also reflected that scholars in the field of educational technology have paid much attention to technology-supported student development, technology-supported learning analytics, and the integration of technology and learning, but have not deeply explored the psychological and behavioral aspects of technological environments. In this regard, *CHB* has performed admirably by focusing not only on the application of educational technology, but also on its impact on human psychology and behavior.

4.1.2. Educational technology trends

Referring to the technology predictions of the Horizon Reports from 2004 to 2022, we divided educational technologies into educational tools, AI technology, data management, extended reality, maker technology, games, and digital resources. Then, we coded 1562 *CHB* educational articles into each key technology cluster. Finally, we illustrated technology trends in *CHB* education research through weighted calculation and M − K trend test, and compared them with the technology trends predicted by Horizon Reports. This not only clearly presents the different key technology trends, but also evaluates the accuracy of the technology predictions. Therefore, there is no doubt that these identified key technology trends are representative. The detailed discussion is given below:

First, educational research trends in AI technology, extended reality, and digital resources are highly consistent with the predictions of Horizon Reports. This is because they offer natural advantages in educational applications. AI technology can monitor and evaluate the learning process through human-machine collaboration, supporting educational decision-making, educational management, and services [60]. Extended reality emphasizes the integration of the virtual world with the real world and focuses on the experiences and needs of learners. Extended reality is characterized by intelligence, interactivity, and immersion, which are conducive to self-shaping and diverse development [61]. In addition, digital resources use the Web as a medium to promote knowledge sharing and give learners the right to learn independently [62]. Open access to quality educational resources advances educational equity and enables high-quality, low-cost mass education possible [63].

Second, educational research trends in educational tools and games are generally consistent with the predictions of Horizon Reports. The acquisition of educational tools is becoming easier and cheaper and has always influenced teaching and learning. The rapid spread of COVID-19 highlighted the significance of educational tools, adding a new dimension to their application. In contrast, games emerged later and developed more slowly in the educational field due to difficulties in integrating games into teaching. For instance, games are more costly to develop and update, and their use places greater demands on teachers and students [64,65].

Third, educational research on data management and maker technology presents specific challenges. Although Horizon Reports have called for the adoption of these two, significant obstacles to their implementation have been encountered. Cloud computing, data security, the Internet of Things, and blockchain all incur extremely high building and maintenance costs [66,67]. Few schools and programs have established complete data management systems for teaching and research. In addition to the high cost of maker technology, training teachers and students takes a significant amount of time, making it difficult to implement maker education on a large scale [68].

Finally, we identified potential themes such as psychology and behavior in technological environment. These topics were not the focus of Horizon Reports. The technology itself and the applications got more attention. However, Horizon Reports didn't completely ignore the relationship between technology and humans. 2021 Horizon Report (Data Security) mentioned student data privacy and governance [51]. It is the first time the impact of technology appeared as a prediction in Horizon Reports. Then, professional development for hybrid/remote teaching was reported in 2022 Horizon Report (Teaching and Learning) [69]. 2022 Horizon Report (Data and Analytics) reported data literacy training, DEI for data and analytics, assessing and improving institutional data and analytics capabilities [52]. These suggest that human psychology and behavior in technological environment will be important themes in future research on educational technology. In summary, *CHB* educational studies reflect the true values and trends of educational technology and can provide appropriate experiences and references for educational practice and research.

4.2. Implications and suggestions

Based on the findings of the bibliometric analysis, we identified an immediate influence of AI technology, extended reality and digital resources on education, a moderate influence of educational tools and games, and a delayed influence of data management and maker technology. This provides several implications for the design and use of educational technology. First, smart learning spaces incorporate a variety of technologies such as AI, extended reality, digital resources, and educational tools [70,71], which is a promising direction for future educational technology research and application. Second, the availability and usability of educational technology largely determines the depth and breadth of application. In other words, the development and design of educational technology should consider the cost, efficiency, and experience of application [72,73]. Third, research and practice in educational technology are influenced by social shifts such as the COVID-19 pandemic and the release of ChatGPT [11]. Therefore, researchers and educators should be sensitive to social shifts, which will benefit them in grasping current hot issues to advance the application of educational technology.

In addition, we provide insights into potential research themes. Technology is an indispensable component in education. However, technology inevitably negatively affects students' psychology as well as induces bad behavior, such as cyberbullying, anxiety, and Internet addiction [74,75]. To overcome this dilemma, teachers should choose appropriate technology, design reasonable activities, and evaluate students' cognitive load and individual differences when preparing lessons [76–78]. Teachers should encourage students to personally solve problems and guide them in using the Internet in a civilized manner to prevent Internet addiction [79,80]. Additionally, teachers should focus on developing students' self-efficacy and metacognitive skills to promote better self-management and self-regulation [81,82].

4.3. Limitations and future research directions

Although this study presents technology trends in human educational behavior, some limitations remain. First, the data from the *CHB* are highly representative but do not cover all publications in educational technology research. Future studies should expand the data sources by including more authoritative journals in the field of educational technology. Second, we only included data until 2022 because the literature in 2023 is not yet fully available. We will continue to track educational technology trends in the future. Third, although bibliometric analysis has unique advantages in large-scale data processing, publication screening, and technology identification still require manual processing, which is time-consuming and laborious. Therefore, we suggest proposing a more efficient method for fully automated screening and identification. Finally, the selection of educational articles and clustering of educational technologies may be subjective. After several discussions, the four authors determined the final sample and coded the study to overcome these difficulties. Future studies will continue to deepen models based on big data and artificial intelligence and promote interdisciplinary collaboration. Meanwhile, we will combine theoretical models from cognitive science and other fields. This will enable us to develop more comprehensive and practical scientific explanatory frameworks and models, consequently propelling the field of educational technology forward.

5. Conclusion

Through bibliometric, visualization, and content analysis, this study systematically reviewed the current state of educational research and technology trends in the *CHB*. The results demonstrate that the *CHB* is increasingly focusing on the quality of publications, with the United States of America and the Netherlands providing the majority of the research forces. The cooperation among countries, institutions and authors is close, but limited by their geographic locations. Research themes focus on technology-supported student development, technology-supported learning analytics, integration of technology and learning, and psychology and behavior in technological environment. In addition, this study identified seven types of educational technologies through the predictions of the Horizon Report: educational tools, AI technology, data management, extended reality, maker technology, games, and digital resources. Based on the predictions, we analyzed and discussed educational technology trends in *CHB*. The results showed that the number of publications on educational tools had declined, but it was still an important technology in education. The number of publications on AI technology, data management, extended reality, maker technology and games had increased significantly. There was no obvious trend in digital resources. Finally, we combined the Horizon Reports and *CHB* educational research to conclude advanced technology trends in human educational behavior: an immediate influence of AI technology, extended reality and digital resources on education, a moderate influence of educational tools and games, a delayed influence of data management and maker technology, and the important future research themes on human psychology and behavior in technological environment.

This work is significant. First, it demonstrates a more authentic and objective comparative method based on leading reports and representative literature to analyze educational technology trends. Second, this study identified the current status of educational technology research, which can help educators quickly and accurately identify research development and frontiers. Third, seven categories of educational technology were concluded based on the Horizon Reports, providing a picture of educational technology trends. Finally, combining expert predictions and empirical evidence, this study reveals advanced technology trends in human educational behavior and provides a more comprehensive view of educational technology research. In conclusion, this study not only realizes a breakthrough and innovation in research methods, but also provides directions for future research and practice of educational technology.

Data availability statement

The data sets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethical approval

Review and/or approval by an ethics committee was not needed for this study because it solely consisted of a comprehensive review of published literature and did not involve human participants.

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CRediT authorship contribution statement

Jun Liu: Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Funding acquisition, Conceptualization. **Zile Liu:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation. **Cong Wang:** Writing – review & editing, Formal analysis. **Yanhua Xu:** Writing – review & editing, Writing – original draft, Supervision, Software, Resources, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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