Education and Information Technologies
https://doi.org/10.1007/s10639-024-12815-8

Computational analysis of knowledge and complexity trends in educational technology research titles from 1927 to 2023

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Received: 28 July 2023 / Accepted: 24 May 2024

Abstract

This study looked at titles of research papers on educational technology that were published between 1927 and 2023 using computational text analysis. To map research trends, metrics for technology terminology use, network complexity, and knowledge updating rates were used. The findings showed that, despite some fluctuations, titles have become more technologically diverse and interconnected over time, indicating a greater emphasis on technology and interdisciplinarity. Escalating title complexity was visualized using network analysis. Citation patterns revealed that science/engineering and educational technology both update knowledge at comparable rates. This computational analysis shows how the fields of education and technology have been evolving together over time, giving historical context to understand current trends. The study shows how to use data science techniques to map the dynamics of research within a practical domain that connects technology and practice.

Keywords Educational · Technology · Titles · Terminology · Complexity · Century

1 Introduction

Over the past century, adopting new technologies to improve teaching and learning has been a constant goal in education (Cuban, 1986; Saettler, 1990). Early educational films, radio broadcasts, and television struggled to replace conventional teaching methods while offering great but imperfect commitment to transforming education (Benjamin, 1988; Clark, 1983; Cuban, 1986). Visions of

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personalized learning were inspired by the development of computers and multimedia software in the 1980s and 1990s, but schools encountered first and second order obstacles that prevented them from realizing their full potential (Earle, 2002; Ertmer, 1999). The internet increased access to information, but they also sparked worries about misunderstandings of technology in education and suboptimal learning outcomes (Kirkwood & Price, 2013; Oblinger & Oblinger, 2005). Video games and educational technologies have attempted to engage digitally savvy students more effectively, but the results have been mixed (Shaffer et al., 2005; Saarinen et al., 2021; See et al., 2022; Vázquez-Cano et al., 2022).

Questions about the long-term interrelationship between education and technological advancement have been raised in light of this enduring dynamic (Hughes, 2005; Zawacki-Richter & Latchem, 2018). How much have new technologies changed teaching methods, teacher responsibilities, and design of curricula (Cuban, 2001)? How can strategies be devised to promote technology integration and innovation in education (Hew & Brush, 2007)? What technological determinism and alternative conceptual framework can be built for deeper understandings of interplay between technological advancement and education (Oliver, 2011)? This intricate symbiosis calls for close investigation, as Selwyn (2016) points out.

Scholars have used theories like social constructivism, technologic determinism, and actor-network theory to make sense of the relationship between education and technology (Bell, 2010; Oliver, 2011; Kirkwood, 2014; Kang et al., 2007). By combining these viewpoints, one can gain a deeper understanding of how technology and education have developed in tandem while also acknowledging human agency in appropriating tools to suit particular needs and values. Some argue, however, that the successive investment in hardware in schools and the use of technology in education do not correspond to the expected pedagogical benefits promised by research debates and reforms in educational technology. (Gipson, 2003; Toyama, 2011; Vrasidas, 2015).

Research literature patterns can be examined to gain knowledge about how technology is incorporated into education (Bishop et al., 2020; Januszewski & Molenda, 2013; Escueta et al., 2017). Although previous research has looked at the effects of particular tools (Sung et al., 2016; Tamim et al., 2011), there are still gaps in the understanding of macro-level evolution. The process of integrating technology can be clarified by computational, bibliometric, or network studies of patterns of knowledge development and online learning community structures (Jan & Vlachopoulos, 2019; Scanlon, 2021; Valtonen et al., 2022). Successful innovation implementation can be informed by looking at how education research and technological advancement have interacted over the years (Bishop et al., 2020).

In addition to creating new possibilities for learning and instructional methods, new technologies also disrupt established roles, practices, and regulations, necessitating adaptation (Horn & Staker, 2017; Kaliraj et al., 2024). With each new innovation, from film to computers, the cycle of emerging technologies challenging established models has been repeated (Reiser, 2001a, 2001b; Saettler, 1990). Guidelines for successfully integrating emerging technologies like artificial intelligence can be drawn from analysis of previous cycles (Celik et al., 2022; Zawacki-Richter et al., 2019).

Paper titles provide a glimpse into changes in their downloads and citations (Jamali & Nikzad, 2011; Letchford et al., 2015). Prior research studies have shown that titles can encapsulate key topics and scope of the study, reveal research methods and article types, demonstrate subject variations and multiple writing genres, or show distinctive characteristics by using terminologies, concepts, acronyms or punctuation marks such as colon and more (Day, 1998; Jiang & Hyland, 2023; Hartley, 2007; Swales & Feak, 2004; Cheng et al., 2012; Jacques & Sebire, 2010; Wang & Bai, 2007). Title pattern analysis is a useful tool for evaluating the evolution of knowledge (Sahragard & Meihami, 2016; Milojević, 2017; Gnewuch & Wohlrabe, 2017; Yang, 2019).

Analyzing obsolescence rates based on citations in various fields can reveal disciplinary differences in research dynamics in addition to mapping topic changes (Dorta-González & Gómez-Déniz, 2022; Faber et al., 2023; Glänzel & Schoepflin, 1995; McFarland & Pearlman, 2019; Zhang & Glänzel, 2017a, 2017b). The field of applied educational technology sits where education and more technical disciplines converge. If research knowledge incorporates new developments at different rates across these domains, it can be determined by comparing citation patterns. This can outline connections between fundamental and applied research fields and guide the use of technology that is supported by evidence.

Quantifying historical trends clarifies future directions and aids in overcoming integration challenges (Chen et al., 2020; Firmin & Genesi, 2013; Lee & Winzenried, 2009). The analysis of a century's worth of research papers on educational technology is done in this study using computational linguistics techniques. To better understand how technological developments have impacted teaching and learning over time, it would be helpful to trace historical terminology use, complexity changes, and knowledge evolution dynamics. In addition to assisting researchers and educators in identifying gaps in current knowledge and areas that need further investigation, such knowledge can also be used to identify emerging trends and areas of focus in the field. The results would also contribute to the provision of insightful information that guides policy choices, professional development initiatives, and educational practices.

The three main goals of this work are, specifically:

1) Analysis of evolution of technology terminology use in educational technology research titles
2) investigation of complexity evolution in educational technology research paper titles.
3) observation and evaluation of knowledge obsolescence rates between educational technology and science / engineering.

2 Data and methods

Our data was primarily sourced from Wos (Web of Science) (2023) Social Sciences Citation Indexes (SSCI). It should be noted that it is not possible to include all precise and clear terms related to educational technology in the database for searching. For the time being, different synonyms, hypernyms, and hyponyms may be used to describe the same educational technology or a related or particular application.

As educational content is transmitted via radio waves and radio is incorporated into education to support or enhance learning in a learning environment, radio for classrooms can be seen as educational broadcasting. In the database's Education & Educational Research category, it is feasible to represent and search for educational technologies using a number of well-known key terms.

The time range for our searches at the SSCI database was from 1900 to the present. In the category of Education & Educational Research prior to 1920, we searched for "educational film," "silent film," or "film." Although films were first used in schools for educational purposes in 1910 (Hess & Saxberg, 2013), our searches produced zero results. According to general consensus, New York City's Haaren High School first documented the revolutionary use of radio in the classroom in 1923 (Darrow, 1932), and the 1930s and 1940s were the height of radio broadcasting (Lippmann, 2008). To find articles published in Education & Educational Research in 1920s, we used radio as the search topic. There is only one record in the 1929 search result. Our analysis requires more information than this.

We turned to JSTOR (2023) to search key term "radio" in journal research articles on radio applications in schools from the oldest and most prestigious journals such as The Elementary School Journal (1914—2017), The High School Journal (1917—2021), or The Journal of Educational Research (1920—2015). It was unexpected that a majority of articles searched from these journals were devoid of reference lists or citations. Perhaps including citations in their academic writing at the time was not required or common practice. Although these references were few in number, we did find citations for journal articles that were published in 1927 from a few educational journals, including Peabody Journal of Education (1923–2015), The Pedagogical Seminary, and Journal of Genetic Psychology. For the sake of research and comparison, we manually copied and arranged the citations or references that were included as footnotes at the bottom of each page.

We used the key terms as search topics in the category of Education & Educational Research of SSCI and collected all the topical document records that were published within one year and represented a decade. The key search terms have been created or made popular at various points in history as exemplars of educational technology for schools. They included the radio, computer, internet, mobile learning, and so on.

We also downloaded some documents from Wos science or engineering categories that were published in the same years as those in Education & Educational Research of SSCI in order to make comparisons. These science or engineering fields, such as electrical and electronic engineering, computer science, telecommunications, or information science, are closely related to educational technologies or their numerous applications. The search topics, databases, categories, and years are listed below (Table 1).

The downloaded data was raw and formatted records. We created programs to parse, extract, classify, and join various fields of the retrieved records for in-depth observation, comparison, and computation. Documents or articles or papers are interchangeably used in this work to refer to the records that were downloaded from Wos. The 2023 data refers to that of the first half of the year, from Jan to Jun.

We used glossary lookup method to calculate the diversity strength of education and technology in educational technology research titles. We downloaded all technology terms (updated in July, 2023) from The National Institute of Standards and Technology (NIST) Computer Security Resource Center Glossary (NIST, 2023), Gartner Information Technology Glossary (Gartner, 2023), the latest Chatgpt-related glossary (Julian, 2023) and electronic version of Oxford Dictionary of Electronics and Electrical Engineering (Butterfield & Szymanski, 2018). We combined these glossaries or dictionaries, removed the duplicates, normalized each word or phrase and built a comprehensive technology glossary containing 19307 entries. The glossary includes not only single terms like modem, hacker or gamification but also compound terms like Cloud Computing, Internet Of Things (iot) or Reinforcement Learning from Human Feedback (RLHF).

For comparison, we also downloaded Oxford Education Dictionary (Wallace, 2015) and built a database that contains more than 1000 terms in the education field.

Each educational technology research title in the downloaded articles was computed to determine its technology diversity (tech_diversity) metric as below:

$$tech\_diversity = \frac{number\ of\ technology\ terms}{total\ number\ of\ words}$$

For example, a title *Chatbot for continuous mobile learning*. Its tech_diversity is 0.8 (technology terms included in the glossary are *chatbot, mobile, learning*, and *mobile learning*. And total number of words is 5.

Similarly, the following describes educational diversity (edu_diversity):

$$edu\_diversity = \frac{number\ of\ education\ terms}{total\ number\ of\ words}$$

The edu_diversity of the above title is 0.2. There is one term *learning* in Oxford Education dictionary.

We used Social Network Analysis (SNA) and the robust tool Pajek to determine the complexity of educational research titles (de Nooy et al., 2011). A vertex's degree centrality in SNA is equal to the number of edges that connect it. The sum of all vertex degree centrality measurements made within a network is represented by the average degree centrality. In order to calculate network density, we divide the total number of potential edges by the number of edges that are currently present in the network. The degree to which vertices in a network are connected to one another through edges is quantified by this metric. Network all degree centralization indicates "the variation in the degrees of vertices divided by the maximum degree variation which is possible in a network of the same size'' (de Nooy et al., 2011, p. 144). This indicator shows the degree to which the network revolves around its central node. The diameter of a network, which can be used to determine whether it is a small world, is the longest distance between any two vertices in the network. According to Watts and Strogatz (1998), small world networks are distinguished by being both highly clustered, resembling regular lattices, and having brief average path lengths, resembling random graphs. In a small world network, the majority of vertex pairs are connected to one another through just a few vertices, according to Newman (2000).

To build a network, we converted *Chatbot for continuous mobile learning* into chatbot continuous mobile learning by removing stop word such as in, of, for, on, using Buckley-Salton-stopword list (2016). Then we changed the words into their

Table 1 data from 1927 to 2023 (Jan-Jun)

Year	Search topic	Wos category (Edutech)	Records	Wos category (SciEng)	Records
1927	radio	(JOSTOR, Search term: radio)	6	Engineering Electrical Electronic	20
1939	radio	Education & Educational Research	8	Physics Multidisciplinary	18
1949	radio	Education & Educational Research	10	Engineering Electrical Electronic	32
1959	television(s), TV(s)	Education & Educational Research	30	Engineering Electrical Electronic	16
1969	television(s), TV(s)	Education & Educational Research	25	Telecommunications	68
1979	audiovisual	Education & Educational Research	15	Information Science Library Science	7
1989	computer	Education & Educational Research	137	Computer Science Software Engineering	181
1999	internet	Education & Educational Research	83	Computer Science Interdisciplinary Applications	423
2009	interactive	Education & Educational Research	442	Robotics	133
2019	mlearning, m-learning, mobile learning	Education & Educational Research	326	Computer Science Information Systems	50
2023 (Jan – Jun)	chatgpt	Education & Educational Research	39	Computer Science Artificial Intelligence	26

stems *chatbot continu mobil learn*, by incorporating a widely used Porter Stemmer (2006) into our program. The words such as *continuous, continue, continued, continuing continuation, continuity* were converted to the stem *continu*. Stemming reduces vocabulary, normalizes words by combining various spellings of a word into a single form, and normalizes words to make it easier to build models and networks. All the titles were converted into stems for building networks.

To investigate the phenomenon of knowledge aging in educational technology research, we employed the concept of half-life theory proposed by Burton and Kebler (1960). This theory is commonly used to assess the rate of knowledge obsolescence, frequency of updates in books or journals, and advancements within specific academic disciplines (Gilyarevskii et al., 2021; Libkind et al., 2020; Todorov & Glänzel, 1988; Tsay, 2009).

The half-life theory focuses on the median citation age, which represents the number of years required to encompass the most recent 50% of all references in a journal for a specific year. According to this theory, half of the citations come from sources that are newer than the median age, while the other half come from sources that are older.

In our research, we treated all of the journals that were searched under the Wos category Edutech as one journal and all of the journals that were searched under the Wos category SciEng as another journal. For both the Edutech and SciEng categories, we calculated the citing half-life for each year.

We set out to analyze the citing half-life between these two categories to gain insight into how quickly or slowly citations are made in the field of educational technology research in comparison to science and engineering research.

3 Results and discussion

It can be seen that from 1927 to 1939, there is a significant decrease in the edu_diversity (Fig. 1). From 1979 to 2023, edu_diversity remains relatively stable. The tech_diversity shows a steady increase from 0.321 to 0.566 from 1927 to 1949. The values fluctuate but generally remain above 0.27 between 1949 to 1979. It can be seen that from 1989 to 1999, there is a slight decrease in tech_diversity, with the values ranging from 0.427 to 0.378. From 1999 to 2023, tech_diversity experiences a gradual increase. Obviously, the overall change of tech_diversity from 1979 is a long-term upward trend.

It should be noted that between 1939 and 1969, tech_diversity is high in the titles of educational research, or even higher than those after 1979. From 1939 to 1969 of 30 years, the sum of tech_diversity is 2.122, slightly larger than the sum of 1.895 from 1989 to 2019. It indicates that from 1939 to 1969, discussions about the use of radio or television in education were at least as intense as, or even more intense than, those about the use of computers or the internet, which are currently popular.

In Fig. 1, the average_title_length metric represents the average length of titles. Clearly, it is a very long-term upward trend. Especially from 2009 to 2023, there is a significant jump from 10.98 to 14.36. It is not known why such phenomenon occurs.

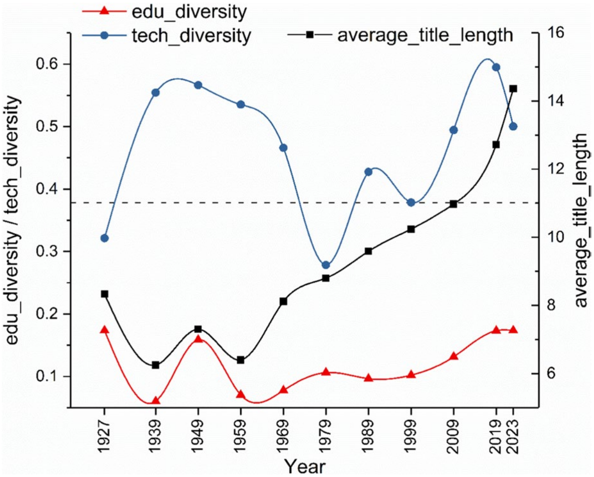


Fig. 1 Edu_diversity, tech_diversity and average_title_length from 1927 to 2023 (Jan – Jun)

Perhaps the subjects being studied have become more complex or interdisciplinary, necessitating longer titles to accurately convey the meanings. On the other hand, the increase in average_title_length over the last 100 years may be influenced by changes in modern citation practices, where authors are more likely to include more detailed information or context within the title to facilitate better understanding and accurate citation. Longer titles may also be used to provide a more comprehensive overview of the study.

Below is the regression model (Adjusted $R^2=0.751$; Anova $F=31.174$, $p<0.05$)

$$averag\_title\_length = -127.197 + 0.069 \text{ year}$$

We conducted Shapiro–Wilk tests on the three data series and they follow normality distributions at the 0.05 level (edu_diversity: statistic = 0.942, $p=0.65$; tech_diversity: statistic = 0.873, $p=0.084$; average_title_length: statistic = 0.908, $p=0.222$). In Table 2, the Pearson Correlation Test shows that there is no significant correlation between edu_diversity and tech_diversity. No significant correlation is found between tech_diversity and average_title_length. There is a significant moderate positive correlation between edu_diversity and average_title_length.

As can be seen in Table 3, the three main themes for 1927 were education, religion, and the influence of country living. With an emphasis on general aspects of education and personal development, these topics probably reflected the social and cultural climate of the time.

By 1939, children were engaging in listening activities and receiving instruction using radio as an educational tool. The use of spoken word on radio demonstrated that it was an oral medium. Radio's importance in educational technology persisted into 1949, with discussions focusing on its application for reading and raising student achievement across grade levels. The relationship between radio and atomic energy was also studied in the classroom.

The impact of television on education and schools was one of the topics in 1959. The use of closed-circuit television for learning or research purposes was also

Table 2 Pearson Correlation Tests[+]

		edu_diversity	tech_diversity	average_title_length
edu_diversity	Pearson Corr	1.000	0.034	0.629
	p	–	0.922	0.038
tech_diversity	Pearson Corr	0.034	1.000	0.050
	p	0.922	–	0.885
average_title_length	Pearson Corr	0.629	0.050	1.000
	p	0.038	0.885	–

[+] $P < 0.05$ is considered statistically significant; 2-tailed test of significance is used

covered in the discussions. In 1969, research on educational technology focused on training delivered via closed television systems or television and radio programs. The use of television in education was highlighted by the reference to it as a teaching tool. Late in the 1970s, audiovisual components were combined to create instructional aids or teaching resources.

In 1989, the general consensus was that computer-based education and learning were primarily used as tools for instruction and teaching, which facilitated learning. Similar to discussions about the "effects" of using radio or television on learning in earlier decades, discussions focused on the impact of integrating this new technology into education. In research paper titles at the turn of the century, terms like the World Wide Web and information technology were frequently used alongside "internet," indicating a keen interest in their use in education.

The use and creation of interactive systems or environments for teaching and learning were the main topics in 2009. By 2019, there was a focus in particular on the use or design of mobile technologies for education or research. 2023 (Jan—Jun) saw principal focus on artificial intelligence and its important implications and impact on future education.

The top 10 stems from the combined 1927 to 2023 (Jan-Jun) data suggest a focus on learning, teaching, and the integration of technology into education, indicating a significant emphasis on mobile learning, student, computer-based instruction, interactive learning environments, or the use of technology to facilitate teaching and studying processes.

Overall, the terms “learn” and "student" consistently emerged as the most prominent concepts throughout this extensive time period, suggesting researchers’ engagement in discussions regarding meeting students’ needs, looking into students’ experiences, and designing technologies to support learning. This is in contrast to specific technology names. The idea of "effect of using new technologies" was also notable, indicating that academics are interested in examining how incorporating emerging technologies into education will affect how well students learn. Researchers looked into the potential effects of technology on students and the educational process. The overall goal of research has remained constant despite the transition from older to newer technologies: examining how new and emerging technologies can be harnessed to improve student learning and the entire educational process.

Stem networks and their properties over time are shown in Fig. 2 and Table 4. It is clear that these network properties change a lot between 1927 and 2023.

Table 3 Top 10 stems from 1927 to 2023 (Jan – Jun) (degc denotes degree centrality)

	1927		1939		1949		1959		1969	
	stem	degc	stem	degc	stem	degc	stem	degc	stem	degc
1	educ	5	radio	22	radio	32	televis	59	televis	74
2	religi	5	educ	8	read	15	tv	32	teach	24
3	countri	4	break	6	educ	11	educ	25	tv	23
4	direct	4	get	6	achiev	9	teach	24	circuit	17
5	dweller	4	spoken	6	atom	9	school	23	close	17
6	futur	4	studi	6	commun	9	effect	22	educ	16
7	leisur	4	word	6	effect	9	studi	20	train	16
8	particip	4	children	4	energi	9	instruct	16	medium	15
9	plai	4	futur	4	explain	9	carpent	15	program	14
10	read	4	instruct	4	grade	9	circuit	15	radio	13
	1979		1989		1999		2009		2019	
	stem	degc	stem	degc	stem	degc	stem	degc	stem	degc
1	audiovisu	63	comput	397	internet	155	learn	453	learn	601
2	materi	27	base	94	us	79	interact	448	mobil	510
3	annot	19	instruct	89	learn	74	base	291	educ	307
4	instruct	19	learn	86	web	63	student	257	student	296
5	analysi	18	effect	77	inform	58	educ	251	base	195
6	resourc	14	assist	71	educ	56	system	223	technolog	177
7	audio	13	school	50	technolog	51	teach	214	applic	158
8	teach	13	teach	48	wide	49	us	208	design	144
9	appendix	12	educ	46	world	47	develop	192	studi	142
10	bibliographi	12	aid	42	base	46	environ	174	languag	135
	2023 (Jan – Jun)		1927–2023 (Jan – Jun)							
	stem	degc	stem	degc						
1	chatgpt	127	learn	896						
2	educ	127	educ	598						
3	intellig	88	mobil	535						
4	artifici	83	student	508						
5	languag	47	comput	486						
6	gener	45	base	483						
7	research	44	interact	473						
8	futur	42	us	374						
9	era	38	teach	339						
10	ai	36	studi	329						

Longer titles typically result in more vertices and more opportunities for connections between them, which can be attributed to the varying complexity or length of titles. In order to gain a deep insight into the overall network from 1927 to 2023, we extracted the subnetwork of K-cores, where each vertex degree is equal to or more than K. In the K-core analysis in Fig. 2, the most significant technologies, concepts, approaches, or research focuses and their relationships are represented by the 88 vertices and their edges, which form the structural framework. These networks are useful for describing how educational technology has developed as a field of study from roughly 1927 to 2023.

Technology-based/applied education is a broad category with many different forms. We lemmatized the raw title data and created bigrams and trigrams. A wide variety of engaging and rich modes of learning have been identified from the bigrams and trigrams, such as interactive learning, distance learning, immersive learning, ambient learning, blended learning, lifelong learning, cooperative learning, programmed learned, reinforcement learning, science learning, vocabulary learning, authentic learning, experiential learning, active learning, language learning, digital learning, contextual learning, online learning, or game-based learning, computer-based learning, cloud-based learning, web-based learning, intranet-based learning, art-based learning, location-based learning, sensor-based learning, project-based

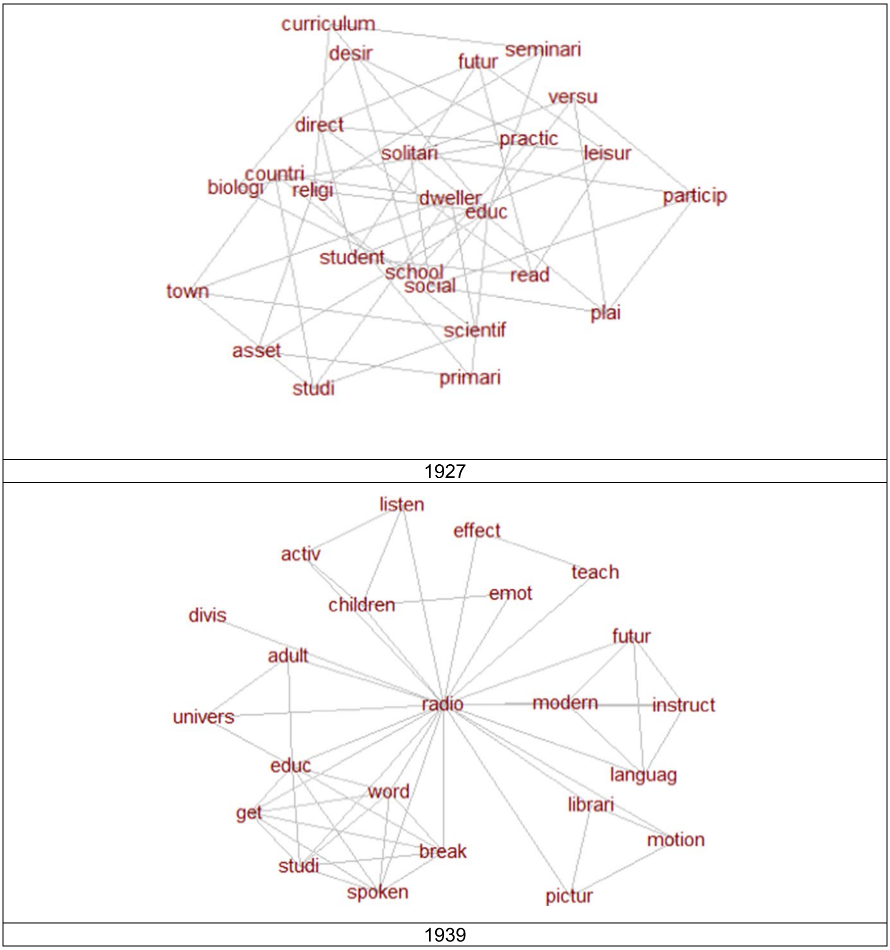


Fig. 2 Stem networks from 1927 to 2023 (Jan-Jun) and k-core subnet

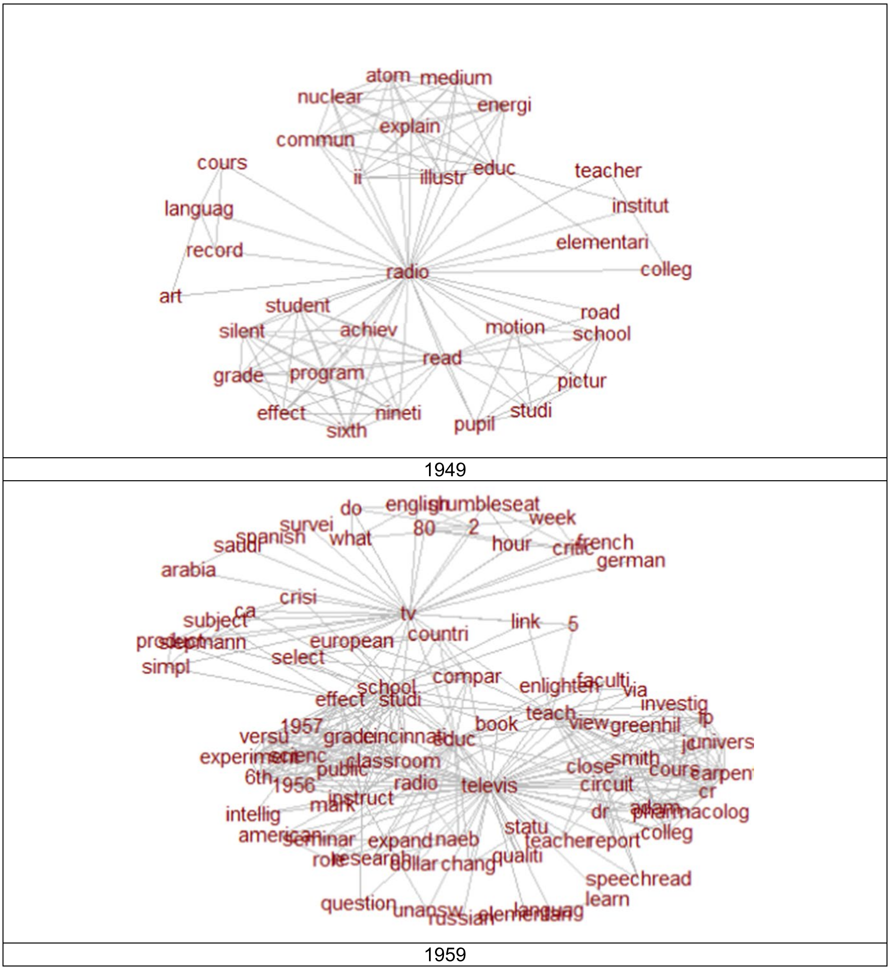


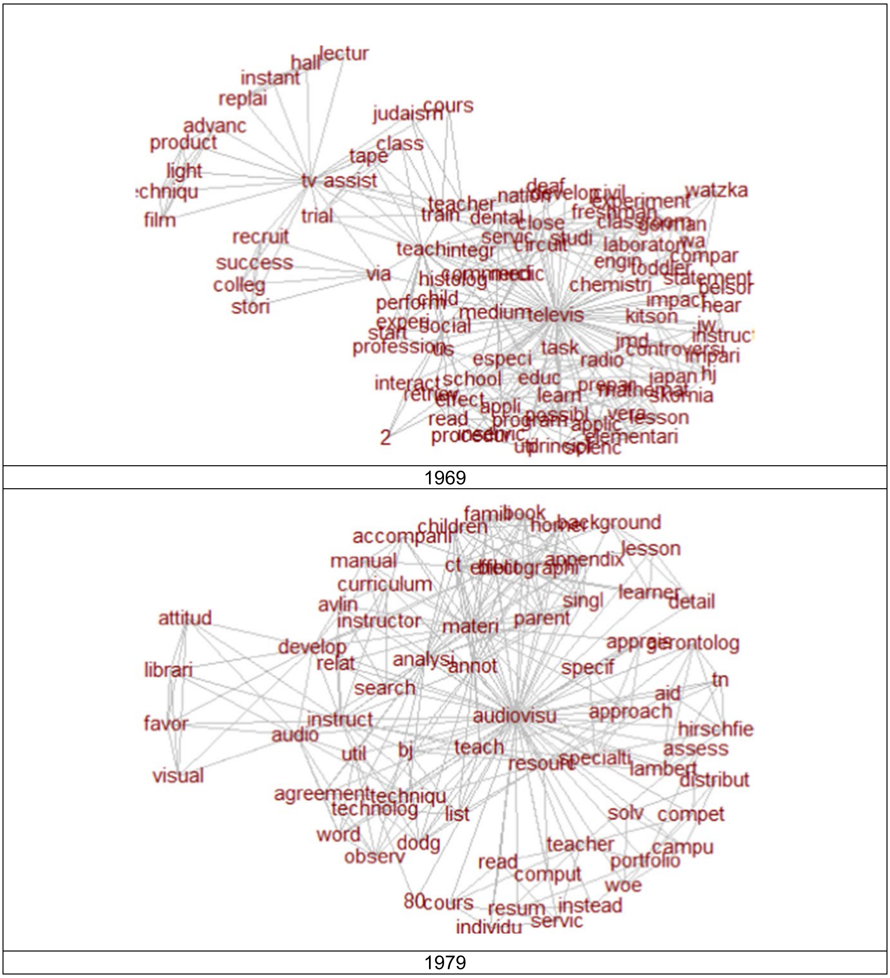
Fig. 2 (continued)

learning, puzzle-based learning, microbiology-based learning, inquiry-based learning, document-based learning, reality collaborative learning, enriched constructivist learning, self-directed learning, guided exploratory learning, mobile ubiquitous learning, personalized virtual learning, compliant virtual learning.

The 2023 data only covers the half year, we performed different linear and nonlinear tests on variables of vertices and edges between 1927 and 2019 and found that they approximately follow the power law distribution (Fig. 3, Table 5):

$$\mathrm{NE} = \mathrm{aV}^{\mathrm{b}}$$

where NE represents the total number of edges; V is the total number of vertices; a and b are constants. In terms of diameter, all the networks are small world networks as it takes less than 6 steps to travel from one side to another in a network. The



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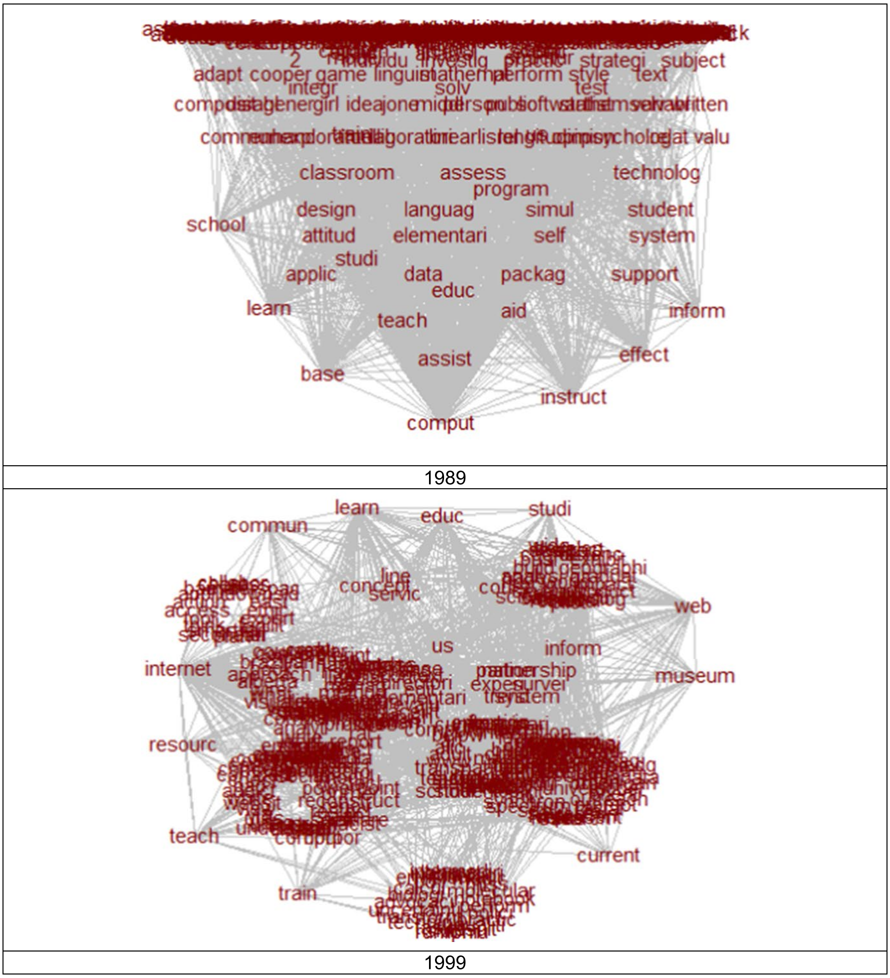
equation could be another valuable way for describing the changes in the number of content words in the titles of educational research papers and their relationships over a period of approximately 10 decades.

Apparently, the degree centrality measures vary considerably according to different numbers of edges and vertices in different decades. They may not be directly compared with each other. The average degree centrality metrics are a useful way for comparing different networks of different decades (Fig. 4(A)). It represents the typical number of connections or links between each stem and other stems in a network. As can be seen, the average degree of centrality is relatively low from 1927 to 1939. This implies that, on average, the stems in the network had fewer



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connections during this time. There is a sizable increase from 1979 to 1989, pointing to greater interconnectivity. The most notable growth occurred between 1999 and 2009, and it continued to grow very quickly in the 2010s.

Overall, the average degree centrality exhibits a steady and strong upward trend throughout the time, indicating increasing complexity of the titles. Below is the linear model (Adjusted $R^2 = 0.803$; Anova $F = 37.738$, $p < 0.001$):

$$A = 0.157y - 335.25$$

where A denotes average degree centrality and y is year.

The network centralization values show how concentrated or unequally connections are distributed within a network. The network centralization in 1927, shown in Fig. 4(B), is only 0.056. This implies that the connections are

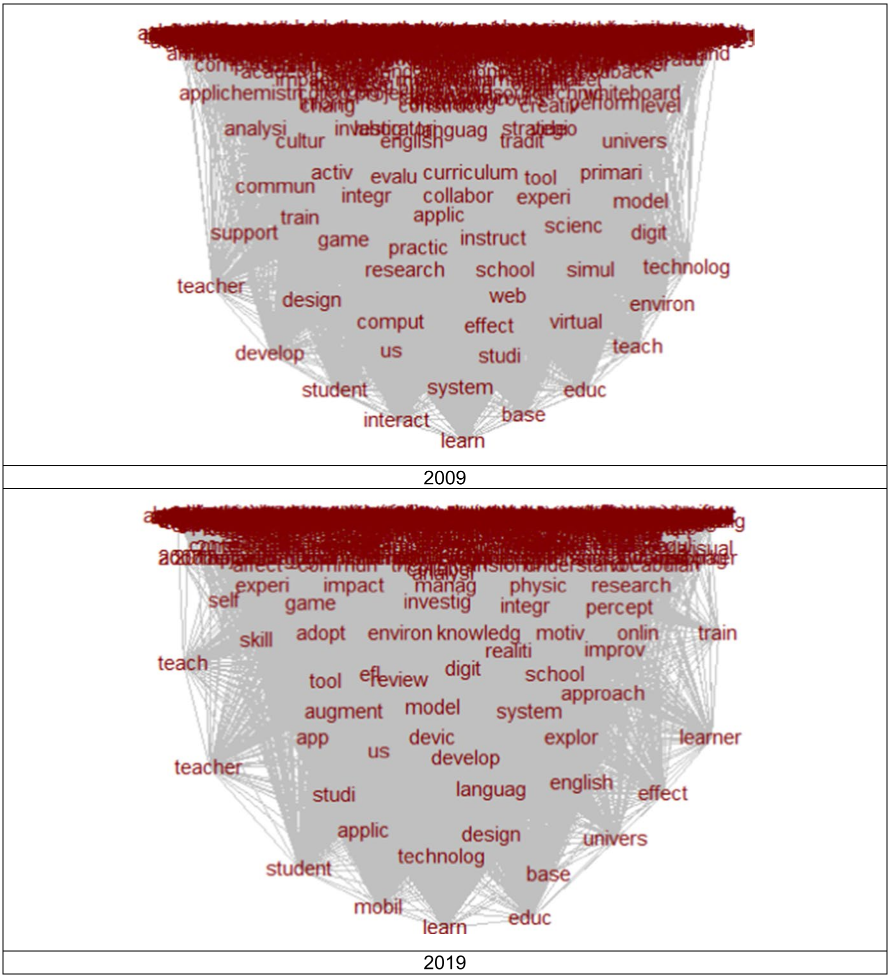

Fig. 2 (continued)

distributed more evenly throughout the network and that the stems are connected to a similar extent. With values ranging from 0.604 to 0.835, network centralization shows a noticeable rise between 1959 and 1979. This suggests that certain stems in the titles of educational research papers became more central and had more connections compared to others, indicating a higher degree of concentration or inequality in the network. The network centralization reaches its maximum value of 0.975 in 1989. It suggests that a small number of stems in the titles of educational research papers became highly central and had significantly more connections than the other stems, indicating an extreme concentration of connections within the network. These stems include compute, base, instruct, and learn, as shown in Table 3. It may be concluded that the stem computer is comparatively the most focal point from 1927 to 2019.

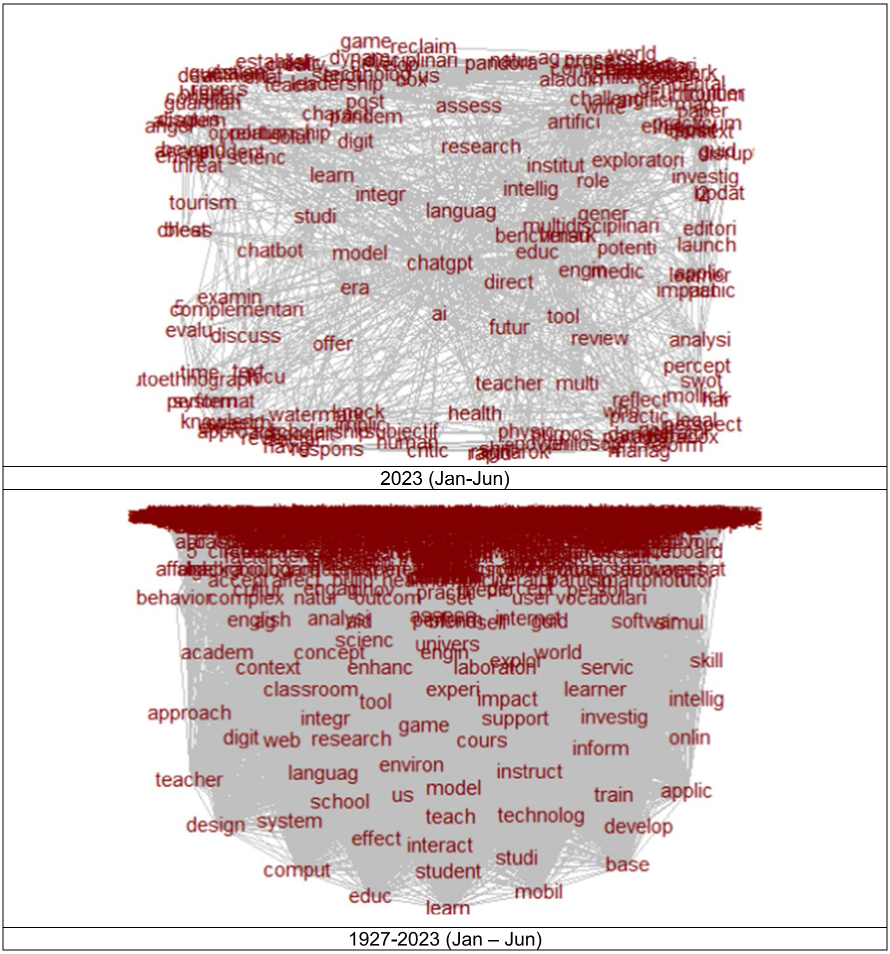

Fig. 2 (continued)

The centralization values fall to 0.481 in 1999 and 0.419 in 2009, respectively. This suggests that connectivity within the network is distributed more fairly and connections are less concentrated. The value of network centralization rises by 2019. This suggests a higher level of concentration compared to the decade before, even though it is not as high as in 1989. In comparison to other words, some of the words in educational research paper titles tended to become more central and had more connections.

The citing half-life for Edutech and SciEng, which ranges from 1 to 7 years, has remained comparatively stable over time (Fig. 5). This shows that expertise in these fields does not become obsolete very quickly. It is clear that the citing half-life has generally gotten longer over time in both fields, pointing to a trend towards slower knowledge obsolescence. The citing half-life of educational technology research papers generally increased between 1949 and 2009, which

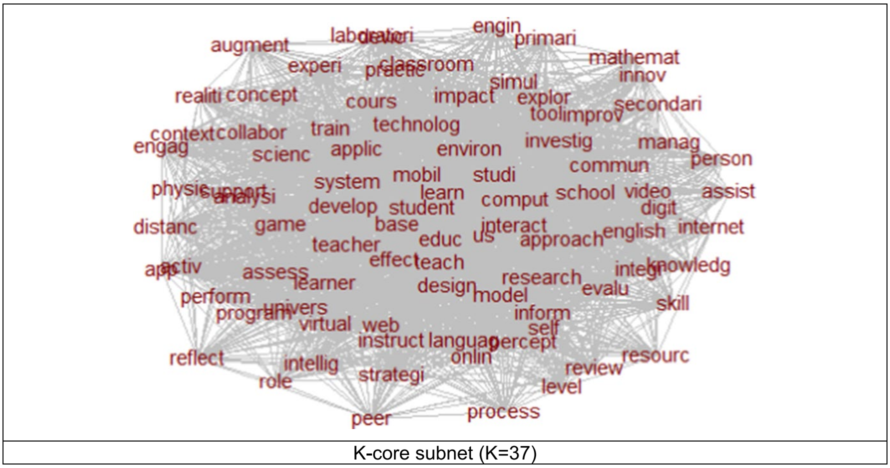

Fig. 2 (continued)

Table 4 Stem network properties

year	vertices	edges	density	diameter
1927	25	47	0.150	2
1939	23	54	0.204	2
1949	33	127	0.233	2
1959	87	360	0.095	4
1969	95	354	0.078	4
1979	68	296	0.128	3
1989	398	2384	0.030	2
1999	303	1636	0.036	4
2009	1036	10,417	0.019	6
2019	797	8449	0.027	4
2023 (Jan-Jun)	169	1255	0.088	4
1927–2023 (Jan – Jun)	1802	22,924	0.014	6
K–core subnet (K = 37)	88	2413	0.623	2

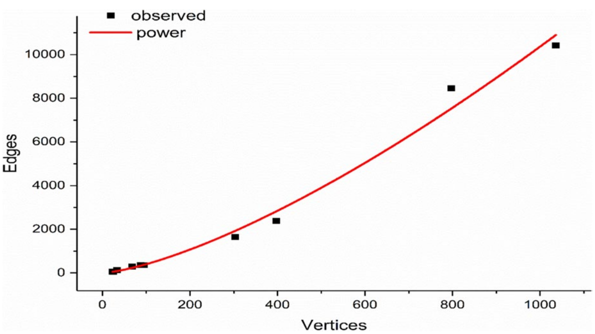

Fig. 3 Relationship of vertices and edges between 1927 and 2019

Table 5 Power law model of vertices and edges between 1927 and 2019

Model	Constant	Parameter Estimate	t	p	R^2	Adjusted R^2	ANOVA	
							F	p
Power	b	1.370	29.481	< 0.001	0.991	0.990	869.128	< 0.001
	a	0.762	4.285	0.003				

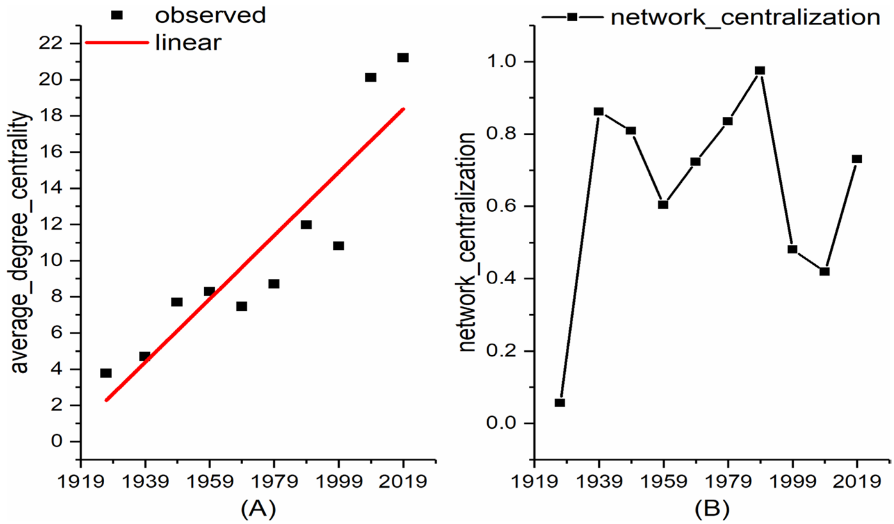

Fig. 4 Average_degree_centrality and network_centralization from 1927 to 2019

suggests that knowledge in the field remained current for longer periods of time. With some variations, the same trend is seen in SciEng research papers. The citing half-life of educational technology research is, from 2009 to 2019, slightly longer than that of SciEng research, at 7–6 years as opposed to 6 years. The citing half-life for both fields in the most recent data point, 2023 (Jan – Jun), is 2, suggesting that they both experience a similar rate of knowledge obsolescence. It seems that the educational technology field is using new sources of information for research at a rate that is comparable to the SciEng field, at least recently.

Table 6 shows that there is no discernible pattern suggesting that one field consistently uses more recent references for research than the other. In comparison to SciEng research papers, there is no compelling evidence that educational technology research is lagging behind or citing much older papers. Overall, there are some similarities between the two fields' citation patterns. It indicates that educational technology research is keeping pace in terms of incorporating new knowledge.

We tested the mean Edutech reference number and the mean SciEng reference number from 1927 to 2023 (Jan-Jun). It appears that their means are not statistically different from one another (Fig. 6, Table 7). This implies that researchers in the fields of Edutech and SciEng typically cite a similar amount of references in their research.

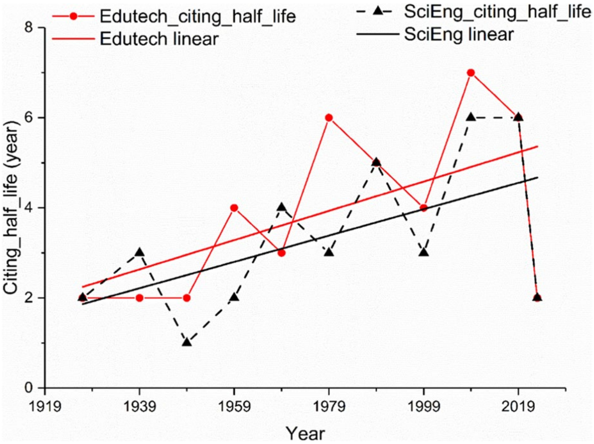

Fig. 5 Edutech_citing half life and SciEng_citing half_life from 1927 to 2023 (Jan – Jun)

Table 6 T-test on the citing_half_life of Edutech and SciEng

	Levene's Test for Equality of Variances			
	F	Sig	t	Sig. (2-tailed)
Equal variances assumed	0.225	0.641	0.718	0.481
Equal variances not assumed			0.718	0.481

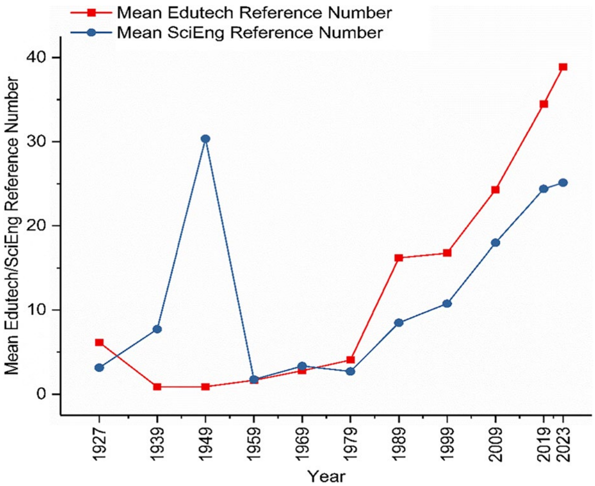

Fig. 6 Mean Edutech/SciEng reference number between 1927 and 2023 (Jan – Jun)

Table 7 T-test on mean Edutech and SciEng reference numbers

	Levene's Test for Equality of Variances			
	F	Sig	t	Sig. (2-tailed)
Equal variances assumed	1.266	0.274	0.198	0.845
Equal variances not assumed			0.198	0.846

4 Conclusion

In this study, computational linguistics methods were used to analyze research paper titles on educational technology of about a century. Technology terminology use, complexity evolution, and knowledge updating rates were quantified as part of the analysis to show how education and technology are related.

The examination of data spanning the years 1927 to 2023 reveals several patterns and trends in the study of educational technology. While tech_diversity exhibits a general upward trend, despite some fluctuations, the edu_diversity metric exhibits a significant decline between 1927 and 1939 before stabilizing from 1979 on. Notably, tech diversity was substantial during the radio and television eras, on par with more recent decades. The debates over the use of radio or television in education were just as heated, if not more so, as those over the widespread use of computers or the internet today.

Average_title_length exhibits a consistent rise, with a notable increase from 2009 to 2023. This might be a result of the complexity of research topics becoming more complex or changes in citation styles that favor comprehensive and detailed titles. The variables edu_diversity and tech_diversity do not significantly correlate. There is no discernible relationship between tech diversity and average title length. The relationship between average_title_length and edu_diversity is statistically moderate and positively associated.

The analysis of popular themes in research titles over time reflects the alterations in society, culture, and technology. The constant emphasis on improving student learning and comprehending the effects of technology on education is highlighted by the recurrent themes of "learn", "student" and "effect of using new technologies." The titles' bigrams and trigrams show a variety of learning modalities.

The research titles' network properties changed significantly over time, with an increase in the number of vertices and connections, which suggests a rise in complexity and interconnectivity. With "comput" (computer) being the most focal point between 1927 and 2019, the network centralization values, which represent the distribution of connections within a network, show that specific keywords ("stems") in the titles became more central over time.

The citing half-lives in Edutech and SciEng research, which ranged from 1 to 7 years, remained comparatively stable, indicating that knowledge in these fields does not become outdated very quickly. The similarities in citing patterns between the two fields show that research in educational technology is keeping up with the pace of incorporating new knowledge. And researchers in the two fields cite about a comparable amount of references in their work.

The study provides a comprehensive historical overview of educational technology research, revealing its evolving focus, growing complexity, and the stable rate of knowledge obsolescence compared to the SciEng field. It offers data-driven insights into the coevolution of education and technology. The use of confined search queries and the exclusive focus on paper titles are limitations of this work. Through expanded data sources and text mining of complete papers, future research could build on these findings.

Acknowledgements We wish to thank the anonymous reviewers for their helpful comments.

Data availability The datasets used are available from the corresponding author on reasonable request.

Declarations

All authors collected and interpreted the datasets. All authors wrote the manuscript and read and approved the final manuscript.

Competing interests All authors declare that they have no competing interests.

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