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Original Article

Systems Thinking in Education: A Bibliometric Analysis

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Abstract

The aim of this paper is to exhibit a bibliometric analysis of systems thinking research in the field of education. A total of 1020 articles from 459 sources indexed in the Web of Science (WoS) database in the years 1984-2022 were used in the analysis. The analysis aims to provide a review of systems thinking research in education by identifying the dynamics of research by presenting a wide in-depth knowledge concerning the periodical process, current situation, and future directions. Research on systems thinking has been acknowledged to demonstrate a significant increase in recent years. Bibliometric data proves that systems thinking research concerning educational studies exhibits a parallel increase too. This is mainly due to UNESCO's declaration of "The Education for 2030 Framework for Action" in 2015. There, systems thinking was defined as a key competency among eight competencies for education for sustainable development. The analysis suggests that systems thinking research in education is mainly directed to subjects of science education and related fields. Although the current research view does not demonstrate an extensive collaboration among researchers worldwide, researchers can be said to acknowledge each other's work sufficiently.

Keywords

Systems thinking
Education
Philosophy of education
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Introduction

Since ancient times thinking holistically was envisioned by many thinkers. From Aristotle to Leibniz, or from Hegel to Husserl, holistic thinking about things, society, spirit, or being in general was an important panacea for solving various theoretical and practical problems that face many thinkers in history. Since the 1950s the term "holistic thinking" gained a new form in the name of "systems thinking" and the concept of "system" became the foremost research agenda. Today "systems thinking" is the very paradigm of holistic thinking (Checkland, 2000).

The reflection on systems became urgent since the start of the information era where the potential production of information in all areas of civilization accelerated exponentially and the residue of this mass production became overwhelmingly complex. According to Senge (1994, p. 54), "for the first time in history, humankind has the capacity to create far more information than anybody can absorb". Moreover, many problems that the global society faces today are due to systemic problems or i.e. "systemic breakdowns" such as global warming and climate change (Senge, 1994).

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Systems Thinking (ST) flourishes from the fact that everything in the world is not a stand-alone entity and that everything is somehow connected in a system (Sterman, 2010). An action in this system of things is not a single action that causes a single reaction but a chain of reactions that causes the system to change. Thus Senge (1994, p. 53) defines ST as a discipline that has a holistic perspective of things and their processes: "it is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static "snapshots"."

The main purpose of ST is to reveal the structures that underlie various complexities in the world (Richmond, 1994; Senge, 1994). Those structures would be an initial point for making complex systems work (Meadows, 2008). In establishing this, ST develops a deep understanding of underlying structures to make reliable inferences (Richmond, 1994). That understanding is crucial for preserving the existence of the system itself.

In practical terms, if the system in question is nature by itself, then it is certainly vital for humanity. Therefore, the ST approach would help to grasp the invisible links between the civilized world and the external environment or nature in general, which will help to reveal and overcome the problems (eg. global warming and climate change, etc.) caused by the scientific and technological advances produced by the civilized world.

Initially, ST have been used mostly in the fields of business, biology, physics, and engineering (York & Orgill, 2020). Today, ST's subjects of research encompass vast areas of interest such as complex organizations, social systems, economics, curriculum design, social work, psychology, addiction therapy, the human body as a system, health, business, banking, personal interrelationships, the global state of affairs, environment, instruction methodologies for groups and teams, decision making and project management, scientific and technological education (Hossain, Dayarathna, Nagahi, & Jaradat, 2020).

More recently researchers in various fields started to employ ST in educational contexts (Clark & Hoffman, 2019; Monat, Gannon, & Amissah, 2022; York & Orgill, 2020). Education is both inextricably embedded within and influenced by economic, cultural, scientific, and political systems (Schuler, Fanta, Rosenkraenzer, & Riess, 2018). Banathy who presents a systems-design view of education and educational change insisted that a systems-design approach to educational improvement should be a foremost issue for education (Banathy, 1991). He (Banathy, 1995) states that educational systems are open systems like other living or social systems and should be analyzed in terms of ST.

The United Nations Educational, Scientific and Cultural Organization (UNESCO) in the year 2015, announced "The Education for All (EFA) Global Monitoring Report" and set goals for the future with the declaration of "The Education 2030 Framework for Action". Education for Sustainable Development (ESD) signified the essence of this declaration. However, the first development on the international scale regarding the concept of sustainability goes back to the 1992 Earth Summit in Rio de Janeiro. That summit was the first initiation for institutionalizing sustainable development projects worldwide (United Nations Conference on Environment and Development [UNCED], 1992). In the year 2000, the UN also declared its Millennium Development Goals, where sustainability was established as one of the key objectives (United Nations [UN], 2000). Afterward, UNESCO launched a plan for promoting worldwide, education for sustainable development through its program The United Nations Decade of Education for Sustainable Development (DESD), which was completed from 2005-2014 (UNESCO, 2005). Following this program, in 2015 United Nations General Assembly declared 17 goals for Sustainable Development Goals that would be active for the year 2015-2030 (UN, 2015). These goals address global problems including, poverty, hunger, health issues, quality education, gender equality, clean water and sanitation, affordable and clean energy, climate change, peace, etc. The declaration of "The Education 2030 Framework for Action" (which will be called "2030 Framework" from now on) states the educational dimension of these goals.

The 2030 Framework notified eight key competencies to accomplish the aforementioned goals. These competencies are stated as systems thinking, anticipatory, normative, strategic, collaboration, critical thinking, self-awareness, and integrated problem-solving competencies, which are key competencies in fulfilling sustainable development (UNESCO, 2016). In the report, the urge for the acquisition of these competencies is foreshadowed by the following conditions:

> As societies around the world struggle to keep pace with the progress of technology and globalization, they encounter many new challenges. These include increasing complexity and uncertainty; more individualization and social diversity; expanding economic and cultural uniformity; degradation of the ecosystem services upon which they depend; and greater vulnerability and exposure to natural and technological hazards. A rapidly proliferating amount of information is available to them. All these conditions require creative and self-organized action because the complexity of the situation surpasses basic problem-solving processes that go strictly according to plan. People must learn to understand the complex world in which they live. They need to be able to collaborate, speak up and act for positive change (UNESCO, 2016).

Today, there are various conceptualizations of ST in many fields of education such as geography, history, biology, physics, and chemistry education (e.g. Ben-Zvi Assaraf & Orion, 2005; Boersma, Waarlo, & Klaassen, 2011; Gero & Zach, 2014; Flynn et al., 2019; Suslov, Salimgareev, & Khammatov, 2017;). Each field aims to enable students to understand the structure and dynamics of complex systems and networks for participating in sustainable development (Schuler et al, 2018). In this view, students that acquire the knowledge and understanding of major natural, social, and economic systems can promote the sustainable development of those systems through their individual, group, or societal behaviors (Schuler et al., 2018).

ST is of paramount importance in education. It enables a comprehensive understanding of educational systems, helps to identify and address unintended consequences, promotes interdisciplinary collaboration, and supports the development of innovative and holistic educational practices. By adopting an ST approach, educators and researchers can navigate the complexities of education and work towards more effective and sustainable educational outcomes. ST promotes interdisciplinary collaboration and the integration of knowledge from different fields (Singam, 2022). Education is influenced by various factors, including social, economic, and technological aspects. ST encourages educators to consider these broader influences and draw insights from disciplines such as psychology, sociology, and economics. This interdisciplinary approach enriches the understanding of educational phenomena and supports the development of innovative and holistic educational practices (Singam, 2022).

Moreover, ST is crucial in addressing complex challenges in education, such as STEM education and sustainability (Mikhaylovsky et al., 2021). These issues require a systems perspective to understand the interconnections and interdependencies between different disciplines and domains. ST helps educators and researchers to develop integrated and holistic approaches to teaching and learning, fostering a deeper understanding of the subject matter and its real-world applications (Elmas, Arslan, Pamuk, Peşman, & Sözbilir, 2021; Schultz, Lai, Ferguson, & Delaney, 2021). It encourages educators to break down disciplinary boundaries and explore connections between different subject areas (York & Orgill, 2020). This approach helps students see the relevance and interconnectedness of various disciplines, fostering a more holistic understanding of the world. One other key importance of ST in education is its ability to promote higher-order thinking skills and problem-solving abilities among students. By examining complex problems and systems, students develop critical thinking, analytical reasoning, and the ability to identify patterns and relationships (York & Orgill, 2020). This prepares them to tackle real-world challenges that require interdisciplinary knowledge and the ability to navigate complex systems. Furthermore, ST helps students develop a sense of agency and responsibility for their own learning (Hmelo-Silver & Barrows, 2006). This promotes self-directed learning and empowers students to become lifelong learners. ST provides a framework for students to analyze and understand complex systems, which is a key aspect of computational thinking (Kafai & Proctor, 2021).

So, ST is of great importance in education. It promotes higher-order thinking skills, interdisciplinary learning, student agency, and computational thinking. By adopting an ST approach, educators can provide students with the tools and mindset necessary to navigate complex systems and thrive in an interconnected world. Therefore, it is important to provide an overview of ST in education and to identify current trends and gaps in the field. In this way, it is expected to provide new ideas to researchers by directing future research. In this respect, this study aims to provide a review of ST research in education by adopting a bibliometric analysis.

Bibliometric analysis is a method used to analyze scientific data and explore trends in a particular field. It can provide insights into the evolution and emerging areas of a field. This analysis involves examining large amounts of objective data, such as citations and publications. The interpretations of this data can be both objective and subjective, leading to a deeper understanding of a specific field of study. Well-done bibliometric studies can provide an overview of the field, identify gaps in knowledge, inspire new research ideas, and help scholars position their contributions (Donthu, Kumar, Mukherjee, Pandey, & Lim, 2021).

The main importance of bibliometric analysis is that it is possible to analyze a large number of studies (Zupic & Čater, 2015). It plays a crucial role in understanding the disciplinary structure of a research field, assessing the impact and influence of publications, identifying trends, emerging topics, and gaps in the literature, supporting evidence-based decision-making, enhancing research evaluation, and informing strategic planning and resource allocation (Leydesdorff & Rafols, 2009; Taris, 2006).

To conduct bibliometric analyses, researchers often use databases such as Scopus and Web of Science (WoS) to retrieve relevant publications (Hyk, Vysochan, & Vysochan, 2022). These databases provide a comprehensive collection of scholarly articles and allow researchers to analyze citation patterns and construct representative datasets (Hyk et al., 2022). However, it is important to note that the scope of the data in bibliometric analyses is limited by the source of retrieval and the composite query used (Chen, 2017). Additionally, the choice of visualization software, such as VOSviewer, can also impact the analysis (Ng, Liu, Shah, Wieland, & Moher, 2023). By conducting bibliometric analyses, researchers can gain insights into the landscape of a research topic and determine the direction of future research. However, it is important to consider the limitations of the data sources and visualization software used in these analyses.

In recent years, the bibliometric method has become popular in the field of education as in many other fields. It is observed that there are many bibliometric studies (Abramo, D'Angelo, & Di Costa, 2009; Hallinger & Kovačević, 2019; Heradio et al., 2016; Martin et al., 2011) in different fields of education. ST, one of the eight competencies of education for sustainability as stated in UNESCO's 2030 Framework, has gained an important status for educational research in recent years. The study by Hossain et al. (2020), which aims to provide a comprehensive insight into the domain of ST, is the only bibliometric study that addresses ST. In the literature, there is only a recent study by Bielik, Delen, Krell, and Ben-Zvi Assaraf (2023) that deal with ST in STEM education. However, in the literature, there is not a bibliometric analysis that addresses ST in education in general. The database search revealed that there is a large number of scientific publications on ST in education. It is thought that having an overview of all of these publications is only possible through a bibliometric analysis. Therefore, this study aims to provide an overview of ST in educational research through a bibliometric analysis of studies published and indexed in the WoS database. In this context, it is thought that bibliometric analysis will play an important role in understanding the disciplinary structure of the field of ST in education, evaluating the influence and impact of scientific publications in the literature, identifying research trends, trending topics, and gaps in the field, and illuminating future research areas related to ST in the educational context.

It is thought that this study will present the general perspective of ST in the field of education, especially to educational researchers working in the fields of ESD, educational administration, science education, educational programs, etc. It is expected that educational researchers will contribute to various theoretical and practical studies based on this study.

This study identifies the dynamics of ST literature and also presents a wide in-depth knowledge to researchers concerning the periodical process, current situation, and future directions. To attain these purposes, the study seeks to find answers to the following research questions.

- What are the efficient aspects of ST literature in the field of education?
- What are the academic trends on matters of ST research in education considering scientific production, mainstream journals and authors, trends evolutions, key themes, and networks?
- What comprehensive lessons can be taken from the current literature for future research?

Method

The bibliometric analysis provides a broader perspective to examine the dynamics of the research field by displaying information such as knowledge accumulation patterns, historical evolution of the themes, most frequent words used in the published material, etc. (Pinto et al., 2019; Zupic & Čater, 2015). In this study to provide the opportunity to summarize a systematic evaluation of ST research in education and analyze the related developments, impacts, and trends of the research field bibliometric analysis method was chosen.

In the data collection process, "system* thinking"[3] and "education" were identified as keywords to identify studies on ST research in education. For this purpose, an online search was pursued in January 2022 by conducting the search query in the topic field of the WoS database which in return resulted in 1579 documents. Afterward, the following refinement criteria were used accordingly: Publication years=All years except for early access (1984-2022); Document type=Article; Language=English. As a result of the search, a total of 1020 articles from 459 sources were accessed for the analysis. The tools used for analysis in this study include the RStudio, the Biblioshiny web app (version 4.0.2), and the VOSviewer software (version 1.6.19).

The techniques for bibliometric analysis are divided into two categories: (1) performance analysis and (2) science mapping. While performance analysis examines the contributions of research components to a particular field, science mapping focuses on the relationships between research components (Donthu et al., 2021). Figure 1 presents both analysis techniques and tools used for this study.

[3] The reason behind the use of “system* thinking” for the search query was because “systems thinking” also appears in the publications in related forms such as “system thinking” and “systemic thinking”.

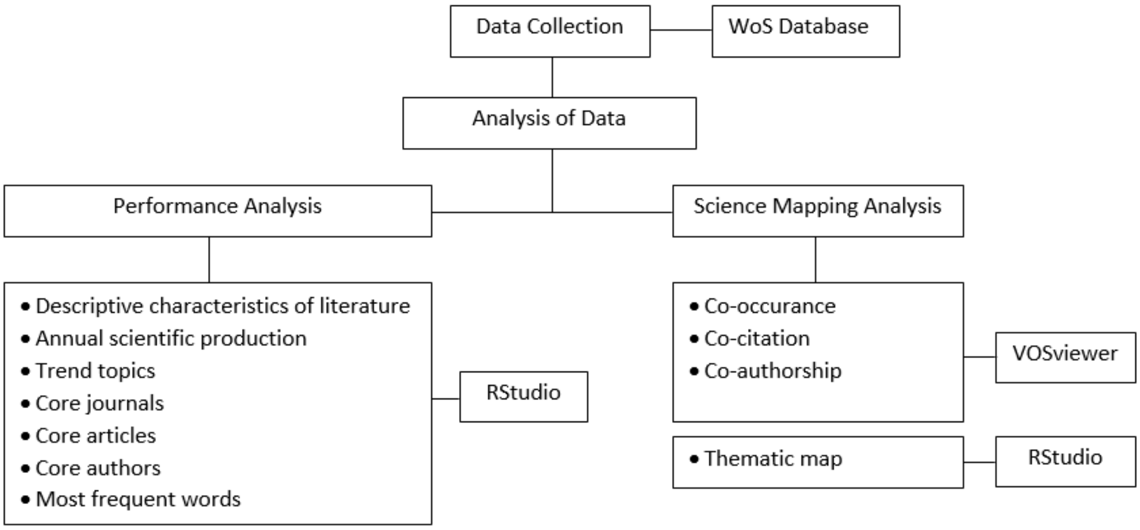

Figure 1. The process of bibliometric analysis

Both performance analysis and scientific mapping were used to achieve the objectives of the study. Performance analysis has been done with RStudio to describe the general characteristics of the literature through sources, publications, and authors, as well as to present information about the total or average numbers of analysis units, productivity, and citation metrics. Science mapping analysis has been done with VOSviewer.

Reliability and validity are also important concepts in bibliometric analysis. A reliable bibliometric analysis should yield consistent results when repeated using the same data and methodology (Hussain, Zakuan, Yaacob, Hashim, & Hasan, 2023). In the context of bibliometric analysis, validity ensures that the analysis accurately captures the relevant aspects of scientific impact, research trends, or other variables of interest (Cronbach & Meehl, 1955).

To ensure reliability and validity in bibliometric analysis, the study should be carefully designed. This includes using reliable and comprehensive databases, such as Scopus or WoS, to retrieve relevant publications (Hussain et al., 2023). It is also important to establish clear inclusion and exclusion criteria for selecting the publications to be analyzed. Additionally, researchers should consider the limitations and potential biases in bibliometric analysis, such as the coverage and quality of the data sources, the choice of indicators or metrics, and the potential impact of self-citations (Bollen, Sompel, Hagberg, & Chute, 2009).

In this study, a reliable and comprehensive database such as WoS was chosen because publications indexed in this database were considered to have the highest impact factors. In WoS the necessary search criteria were determined to distinguish the scientific articles containing ST in education, and reliable software such as RStudio, Biblioshiny, and VOSviewer were used to perform the bibliometric analysis. Thus, the reliability and validity of the study were ensured.

As a result of analyzing the articles in the resulting data set one by one, it was assumed that the studies related to health education, museum education, nursing, etc. were related to education. On the other hand, limiting the language of the publications to English in the formation of the data set and selecting only articles from the publications can be shown as the limitations of the study. In addition, the fact that the year 2023 was not completed on the date of analysis affects the descriptive character of the analysis, so the exclusion of this year can be shown as a limitation of the analysis. Finally, this study covers publications in WoS. The fact that publications in databases such as Scopus etc. are not included in the analysis can be shown as another limitation of the analysis. However, it was observed that almost all of the publications included in the analysis were also scanned in Scopus. For this reason, it is thought that this limitation does not have a significant effect on the results of the analysis.

Results

In this section, the results of the performance and science mapping analyses of ST research in education within the articles published in the WoS database are documented. In the following section discussions and conclusions regarding these results will be exhibited.

Descriptive Characteristics of the Literature

Table 1 summarizes the descriptive characteristics of the literature on ST research in education. The interval that appeared in the research of the bibliometric analysis was from 1984 to 2022. After making certain criteria limitations, a total of 1020 documents were included in the analysis.

According to the gathered data, the annual growth rate of the publications is 13.97 which implies that the research area is dynamic and growing. The citation average per document which is 12.98, indicates that the articles are of high quality and extensively cited by other studies. The average age of the documents in the analysis is 6.59, which emphasizes that the research field is quite new.

Table 1. Descriptive characteristics of the literature on ST research in education

Description	Results
Main Information About Data	
Timespan	1984:2022
Sources (Journals, Books, etc.)	459
Documents	1020
Annual Growth Rate %	13,97
Document Average Age	6.59
Average citations per doc	12.98
References	40822
Document Types	
Article	1020
Document Contents	
Keywords Plus (ID)	1333
Author's Keywords (DE)	2937
Authors	
Authors	2948
Authors of single-authored docs	201
Authors Collaboration	
Single-authored docs	210
Co-Authors per Doc	3.24
International co-authorships %	20.78

Annual Scientific Production

The scientific production of ST in education has increased continuously since the beginning of the millennium (see Figure 2). In the beginning, the increase is slow, but since 2015 more interest accumulated in ST among educational researchers because of recognizing the necessity of using a new thinking skill. This growth in scientific production also highlights the interest of educational researchers to gather more knowledge about ST as a possible solution to bring efficiency and quality to education.

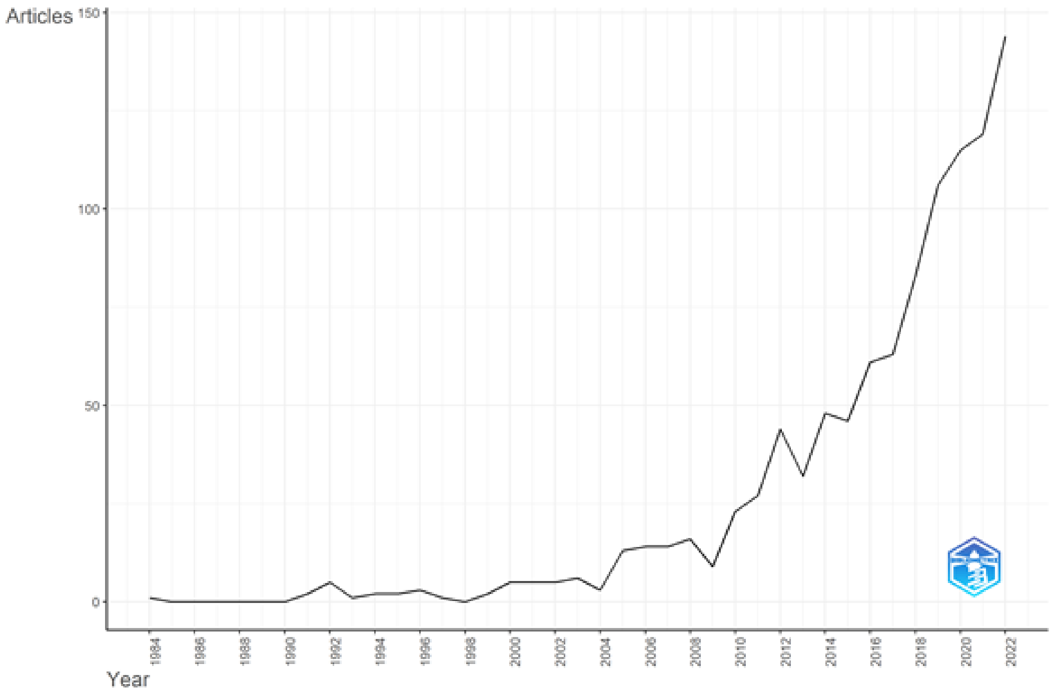

Figure 2. Annual scientific production of ST research in education

This trend can also be explained by the increasing international activities about sustainability. Especially after the declaration of UNESCO's 2030 Framework in 2015 (UNESCO, 2016), the number of publications exhibit an exponential increase. Although the year 2015 may be seen as a cornerstone for spreading the ST research in education, since the United Nations' Millennium Development Goals in September 2000 (UN, 2000), where sustainability was set as a key objective, a steady increase in publications start to begin.

Therefore, it can be said that ST in education as a domain is not saturated yet and is open to various improvements. These results are parallel with the results of a similar study about sustainability by Hossain et al. (2020), which emphasized this growing trend in ST publications from the beginning of the millennium.

Trend Topics

In this study, 2937 authors' keywords were collected from 1020 articles published on ST in education from 1984 through 2022. Figure 3 shows the historical development graph of the most used keywords by the authors. The x-axis of the graph indicates the years and the y-axis indicates the keywords or terms used in the articles. Horizontal lines on the graph represent the evolutionary process and the blue dots represent the average time of the year of the articles published with the corresponding keyword. The dots' size on the graph indicates the frequency of the corresponding keywords. In other words, a bigger circle on the line indicates that more articles that contain the corresponding keyword were published in the time duration. For example, the keyword "systems thinking" in the graph was used intensively between 2016 and 2021, and its peak was in 2019. Similarly, the keyword "sustainability", which was used frequently between 2016 and 2020, was top used by the authors in 2019, while the keyword "higher education", which was used intensively between 2014 and 2020, peaked in 2018.

Figure 3 shows that the longest duration for the keywords was observed for "methodology" and "soft systems methodology". Critical systems thinking which is closely related to ST also appears to be a prevalent keyword in the last decade. ST, sustainability, systemic thinking, and higher education are the key study subjects in the area. Recently health, chemistry education, and STEM (science, technology, engineering, and mathematics education) appear to be hot topics in the research field.

Especially in recent years, it is seen that ST has come back to the agenda and its popularity has increased in the context of concepts such as "sustainability education" and "sustainable development".

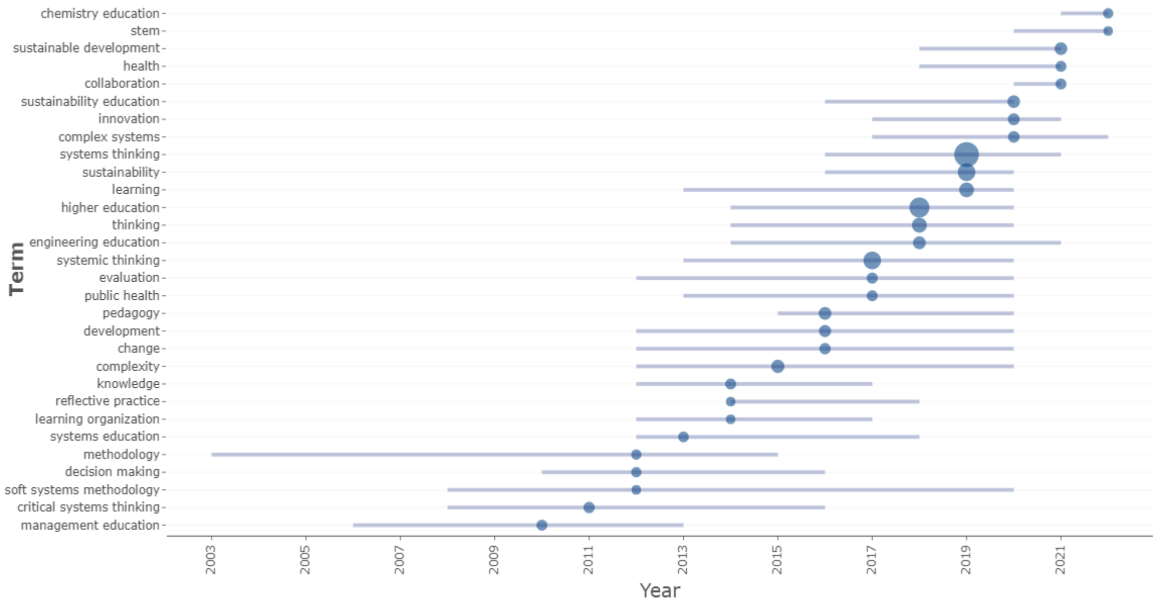

Figure 3. Trend topics analysis based on Author's Keywords in Biblioshiny

Influential Aspects of ST in Education Literature

Core Journals

To find the core journals of the research field source impact and Bradford's Law analyses were used in the study. The table below (Table 2) lists the top ten journals based on the h-index of the articles on ST research in education published in those journals. In each row of the list m and g-indexes, total citation counts (TC), number of publications (NP), and publication starting year (PY-start) are also shown. The h-index indicator is found to be better for predicting future success compared to other indicators (Hirsch, 2007).

Table 2. Top ten journals according to source impact

Journals	h-index	g-index	m-index	TC	NP	PY-start
Journal of Chemical Education	18	25	1.385	787	51	2011
International Journal of Sustainability in Higher Education	12	19	1.000	366	25	2012
Journal of Cleaner Production	12	14	0.857	655	14	2010
Sustainability	12	19	1.000	420	51	2012
International Journal of Science Education	11	18	0.478	412	18	2001
Academic Medicine	9	11	0.281	273	11	1992
Systems Research and Behavioral Science	9	16	0.360	286	30	1999
Journal of Research in Science Teaching	8	10	0.381	683	10	2003
Systems Practice and Action Research	7	10	0.292	165	31	2000
Systems	7	8	0.700	89	13	2014

According to Table 2, it is seen that the first source concerning the h-index is the *Journal of Chemical Education*. A total of 105 citations were received among the 254 articles listed in the table. However, since the specific citation style of each scientific discipline is considered in calculations of the h-index (Bornmann & Daniel, 2007), it would not be correct to interpret this index in an interdisciplinary study. While calculating the citation performance in the g-index, the most read articles are given more importance in the calculations (Egghe, 2006). According to the g-index, *Journal of Chemical Education* with a value of 25, is again the highest source. 150 of the 254 publications are listed in the g-index. 25 of those 150 publications belong to the articles published in *Journal of Chemical Education*. The m-index is calculated by dividing the h-index by the number of years the journal is active. *Journal of Chemical Education* ranks first again in the m-index with a value of 1.385. When the sources are analyzed in terms of the total number of citations (TC) and total number of publications (NP), it is seen that *Journal of Chemical Education* ranks first with 787 citations and shares first place with the journal "Sustainability" with 51 of the 254 articles published in the top 10 journals in Table 2. Accordingly, it can be said that, although its first publication dates (PY) back to 2011, the most effective journal in the research field is the *Journal of Chemical Education* and the most effective studies are published there.

Another remarkable point about Table 2 is that although some journals have published a small number of articles, they have a high number of citations and high impact ratios (h-index, g-index, etc.) in the field. For example, the *Journal of Cleaner Production*, with 14 publications, received citations from 655 independent publications and had a high impact in the research field with an h-index of 12 and a g-index of 14. Similarly, *International Journal of Science Education*, with 18 publications, was cited by 412 independent publications and had an h-index of 11 and a g-index of 18.

Table 3. Journal ranking according to Bradford's Law analysis.

Journals	Rank	Freq	Zone
Journal of Chemical Education	1	51	Zone 1
Sustainability	2	51	Zone 1
Systemic Practice and Action Research	3	31	Zone 1
Systems Research and Behavioral Science	4	30	Zone 1
International Journal of Sustainability in Higher Education	5	25	Zone 1
International Journal of Science Education	6	18	Zone 1
Education Sciences	7	14	Zone 1
Journal of Cleaner Production	8	14	Zone 1
Systems	9	13	Zone 1
International Journal of Engineering Education	10	12	Zone 1
Kybernetes	11	12	Zone 1

Table 3 demonstrates the rankings of the journals based on the analysis of Bradford's Law, which defines the distribution of the articles in relevant journals (Garfield, 1980). This analysis indicates the core sources in the research field. When the sources are ordered by their publication frequency (Freq) from ascending to descending, the journals were classified into three zones. Journals in Zone 1 represent the core journals in ST research articles in education. According to this analysis, 19 of 459 journals are listed in Zone 1. The top ten journals in Zone 1 are shown in Table 3 however *International Journal of Engineering Education* and *Kybernetes* journals both share a frequency number of 12, thus they are both listed in the table. *Journal of Chemical Education* is again the top journal in this analysis.

According to the list in Table 3, journals focusing on science education, STEM, sustainability, etc. have a higher frequency of publications on ST. Therefore, it can be said that ST is a research topic that is used more in the field of science education. The findings in the rest of the study and the literature in this field also confirm this finding.

Core Articles

The core or leading articles in ST research in education can be determined by the number of citations the articles have received. The number of citations of an article can be calculated in two ways. The first way is to measure the total citation score that an article receives from all publications in the entire WoS database, which is called the global citation score (GCS). The second way of calculating the citation score is by counting the citations of an article made by the publications in the dataset within the scope of the ST research in education, which is called the local citation score (LCS) (Aria & Cuccurullo, 2017). Table 4 lists the top ten articles according to LCS and GCS.

The most cited two articles according to the LCS are "Development of system thinking skills in the context of earth system education" (Ben-Zvi Assaraf & Orion, 2005) and "Systems thinking skills at the elementary school level" (Ben-Zvi Assaraf & Orion, 2010a). Both articles were authored by Orit Ben-Zvi Assaraf and Nir Orion and they were also extensively cited by other research studies outside the focus of this study. Ben-Zvi Assaraf and Orion in five years intervals published these two articles and their research subject and methodology are almost the same in both publications. The sample population in the former is junior high school students and in the latter is elementary school students. In both articles, the authors used the water cycle in the context of earth system education. Thus these articles became especially influential in science education, such as biology, chemistry, and STEM. Ben-Zvi Assaraf and Orion are also ranked in the top ten influential authors of ST research in education, which can be seen in the section below. This data also proves the influence of these articles.

The third most cited article by LCS is titled "Promoting systems thinking through biology lesson" by Werner Riess and Christoph Mischo (2010). This article is an evaluation of different approaches for promoting ST in the field of Education for Sustainable Development. The authors of the article used the biology lesson as the context of their evaluation but the keywords (i.e. teaching methods, problem-solving, systems theory, evaluation, science education) used by the authors indicate that their concern is in general science education.

Other articles listed as the most cited documents indicate that studies about acquiring ST skills in education mostly concern subjects of science education: chemistry, biology, ecology, geology, etc. Besides these, an article by Marco Rieckmann (2012) which is the most globally cited article points out an interest in ST education at the higher education level. Rieckmann (2012) advocates that the most relevant competencies that should be fostered in higher education are ST, anticipatory thinking, and critical thinking.

Table 4. Local Citation Score (LCS) and Global Citation Score (GCS) of the publications

Article	Author(s)	Source	Year	LCS	GCS
Development of system thinking skills in the context of earth system education	Orit Ben-Zvi Assaraf, Nir Orion	Journal of Research in Science Teaching	2005	95	271
System thinking skills at the elementary school level	Orit Ben-Zvi Assaraf, Nir Orion	Journal of Research in Science Teaching	2010a	31	88
Promoting systems thinking through biology lessons	Werner Riess, Christoph Mischo	International Journal of Science Education	2010	28	66
Future-oriented higher education: Which key competencies should be fostered through university teaching and learning?	Marco Rieckmann	Futures	2012	25	394
Four case studies, six years later: Developing system thinking skills in junior high school and sustaining them over time	Orit Ben-Zvi Assaraf, Nir Orion	Journal of Research in Science Teaching	2010b	24	65
The feasibility of systems thinking in biology education	Kerst Boersma	Journal of Biological Education	2011	23	32
Effect of knowledge integration activities on students' perception of the earth's crust as a cyclic system	Yael Kali, Nir Orion, Bat-Sheva Eylon	Journal of Research in Science Teaching	2003	20	76
Applications of systems thinking in stem education	Sarah York, Rea Lavi, Yehudit Judy Dori MaryKay Orgill	Journal of Chemical Education	2019	19	49
Integrating the molecular basis of sustainability into general chemistry through systems thinking	Peter G. Mahaffy, Stephen A. Matlin, J. Marc Whalen, and Thomas A. Holme	Journal of Chemical Education	2019	17	39
Systems modelling and the development of coherent understanding of cell biology	Roald P. Verhoeff Arend Jan Waarlo Kerst Th. Boersma	International Journal of Science Education	2008	16	62

Core Authors

Table 5 lists the core or most influential authors of ST research in education based on their h-index numbers. In each row of the table, the g-index (a variant of the h-index that indicates the most-read paper) (Egghe, 2013), the m-index (another variant of the h-index that displays the h-index per year since its first publication) (Hirsch, 2005), the total number of citations (TC), the total number of publications (NP) based on the WoS database, start year of the publications (PY-start) of each author are also given.

Table 5. Top ten authors in ST research in education

Authors	h-index	g-index	m-index	TC	NP	PY-start
Dori, Y. J.	7	9	0.304	305	9	2001
Ben-Zvi Assaraf, O.	6	6	0.316	462	6	2005
Gonzalo, J. D.	6	9	0.857	167	9	2017
Houston, D.	5	6	0.263	196	6	2005
Orgill, M.	5	5	1.000	191	5	2019
Orion, N.	5	6	0.238	526	6	2003
Zoller, U.	5	5	0.217	150	5	2001
Ahmed, S.	4	5	0.571	37	5	2017
Camelia, F.	4	4	0.571	25	4	2017
Ferris, T. L. J.	4	4	0.571	25	4	2017

Dori is the first on the list of authors with the highest h-index. The total number of articles published by Dori and her collaborators starting from 2001 in the field is 9 and received a total of 305 citations from other studies. This data proves the importance of Dori and her collaborators' work in the field. Dori has specialized especially in science and technology education, and recently published about engineering education. According to the g-index, Dori and Gonzalo lead this category, and their top-cited articles in the data set are cited at least 9 times. When sorting by the m-index, Orgill is the first on the list. This finding proves that Orgill in a short period contributed much to the field. Ben-Zvi Assaraf and Orion both receive the most number of citations from other articles with 462 and 526 citations respectively. However, both author's h-index and g-index values did not place them at the top of the list.

Most Frequent Words

Frequently used words in ST research in education are demonstrated in Table 6. The table has four parts named, Keywords Plus, Author's Keywords, Title, and Abstract. In almost all parts except Keywords Plus, "systems thinking" is the most common word used. In Keywords Plus, "systems thinking" is ranked fourth after education, science, and knowledge. The three most frequent words in Keywords Plus are listed as education, science, and knowledge. This indicates that in general indexed keywords concerning science education come into the front. Sustainability and its related concepts appear to be highly appreciated by the Author's Keywords, Title, and Abstract of the publications in the research field. Words related to chemistry appear to be common among the word list which indicates that educational research concerning chemistry is an important subject in the field. Words like "higher education", "engineering education", and "medical education" indicate that ST in education is focused on research in university-level education. Issues concerning "public health" and "patient safety" point out the medical education aspect of ST research. Also in general, ST as a key competency of thinking skills is related to every concern about thinking education.

Table 6. Most frequent words is ST research in education.

Keywords Plus		**Author's Keyword**	
Words	**Occurrences**	**Words**	**Occurrences**
Education	176	Systems Thinking	326
Science	113	Education	112
Knowledge	65	Sustainability	98
Systems Thinking	62	Systems	71
Students	61	Higher Education	52
Thinking	56	Thinking	48
Skills	54	Learning	44
Framework	49	Curriculum	35
Management	41	Education for Sustainable Development	26
Model	39	Green Chemistry	23
Title		**Abstract**	
Words	**Occurrences**	**Words**	**Occurrences**
Systems Thinking	239	Systems Thinking	1230
Sustainable Development	35	Public Health	169
Public Health	25	Sustainable Development	167
Thinking Skills	18	Thinking Skills	105
Green Chemistry	17	System Thinking	99
Engineering Education	16	Climate Change	78
Chemistry Education	15	Chemistry Education	76
Medical Education	14	Systemic Thinking	71
Thinking Approach	14	Thinking Approach	71
Patient Safety	13	Green Chemistry	68

Conceptual Framework

Co-occurrence Network

The co-occurrence of the analysis of the keywords, in other words, co-word analysis has been widely used to analyze the main research topics and determine the innovative themes for future research (Merigó, Pedrycz, Weber, & de la Sotta, 2018; Mao, Guo, Fu, & Xiang, 2020). This analysis type has been developed to conceive the significance of the relations between keywords used in the publications of a particular research field (Ferreira & Robertson, 2020; Radhakrishnan, Erbis, Isaacs, & Kamarthi, 2017). The occurrence of the keywords, the total number of links, and the strength are the parameters to understand the connection strengths of the keywords. Therefore, co-occurrence analysis, makes it straightforward to understand the particular research directions in the field which is under bibliometric analysis. The node sizes in the graph show the frequency of the keywords and keywords from a similar field or with similar features are categorized into the same cluster which represents a research domain.

In this study, among 1020 articles the most frequent keywords used were analyzed by VOSviewer software. In the process of co-occurrence analysis, after the minimum number of occurrences of a keyword has been set to 5, 116 of the 2828 keywords are displayed in the network indicating 800 links with total link strength of 1924, and they are divided into six clusters. As a result of the co-occurrence analysis, six clusters represented by different colors were identified. The resulting graph can be seen in Figure 4.

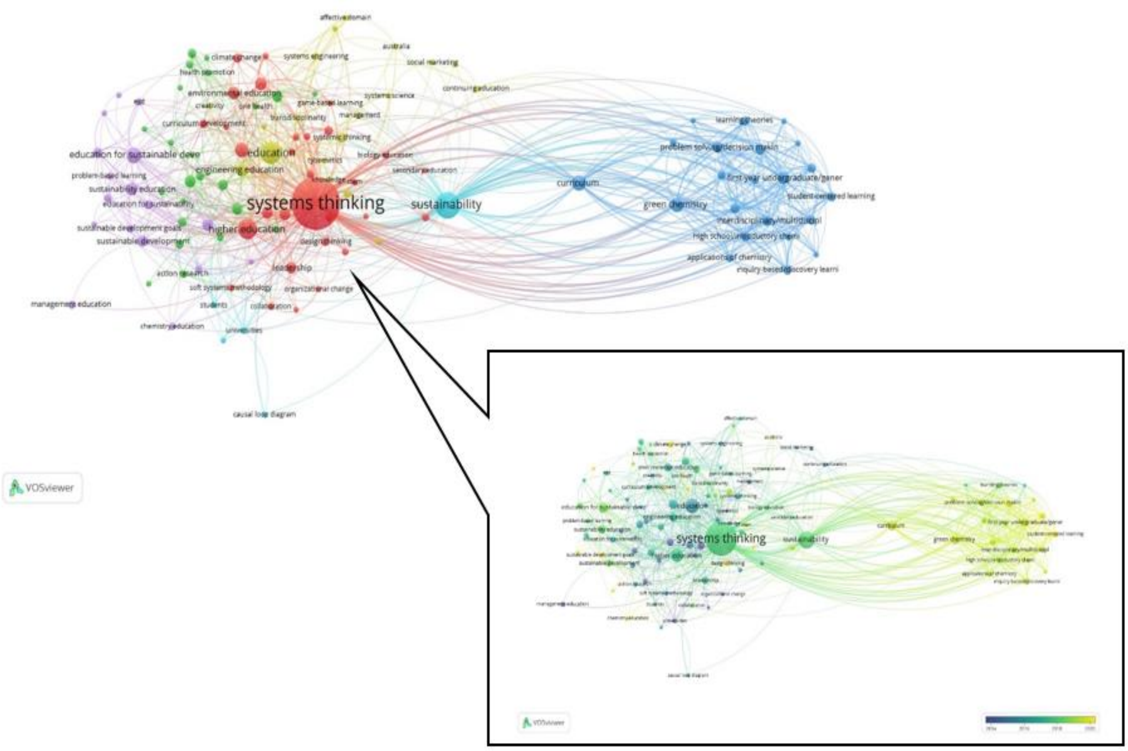

Figure 4. Co-occurrence network with overlay visualization

The first red cluster represents the main subject "systems thinking" and the concepts directly related to ST. These concepts can be listed as "system", "system dynamics", "design thinking", "complexity", and "leadership". Although the concepts of "pedagogy" and "experiential learning" have come to the fore in the green cluster, these concepts are included in this cluster together with the terms related to health concerns, rather than their general usage. The reason behind this is especially due to the use of ST in recent years in education processes in the field of health and medicine. The third blue cluster represents the recent research trend in chemistry. It is seen that the studies on ST in the field of chemistry have increased considerably in the last few years. With the entry into the force of sustainability policies, studies based on ST also come to the fore in chemistry education. In the fourth yellow cluster, it is seen that there are certain concepts such as "mental models", "continuing learning", and "creativity" as well as "education". This cluster also includes the engineering studies associated with these concepts. Engineering can be considered a field where ST has been used extensively for many years. Systems engineering, engineering education, cybernetics, and systems science are emerging concepts related to this field. The fifth purple cluster represents the research field where education meets sustainability. The concept of sustainability is not relatively new. However, in recent years the development of sustainability and the definition of new competencies in the field of education have been the most popular topic in many disciplines. ST is one of the most important competencies for establishing sustainable development. The last turquoise cluster is the central cluster representing sustainability. In addition to sustainability, since concepts such as "competencies", "students", and "universities" are related to the field of education, this cluster can be included in the purple cluster.

Thematic Map

Thematic map in the bibliometric analysis is used to analyze the importance and development of the research themes based on the density (y-axis of the graph) and the centrality (x-axis of the graph) of the themes. The centrality measure indicates the degree of correlation among different topics signifying the importance of the topic, and the density measure gives the development of the number of publications for the corresponding theme in time.

Figure 5 below gives the thematic map of ST research in education. The graph has four quadrants each indicating different meanings concerning the importance and development of the theme under focus. For instance, themes in the lower left part are emerging or declining themes. The lower right part of the map resides in the basic themes. These are high in centrality but low in density. This means that these themes have been studied the most in the past. The upper left part of the thematic map represents lower centrality and high-density themes. These themes are highly developed however their low centrality signifies that they are isolated. Lastly, the upper right part of the map represents the essential and developed themes which are called motor themes (Ahmi, 2021).

The thematic map in Figure 5 is constructed based on a full-time span from 1984 to 2022. In total 350 top keywords were used in the analysis. In Biblioshiny the themes shown in the clusters are set to the minimum frequency of 8 and the number of representative labels in each theme is set to 3.

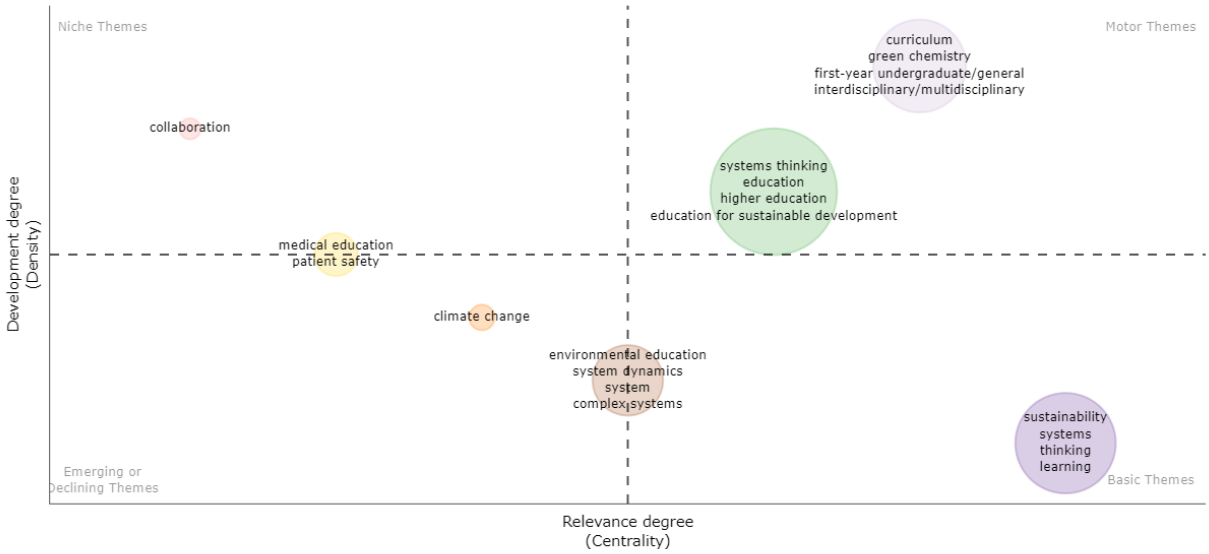

Figure 5. Thematic map of ST research in education.

In the basic themes quadrant, themes related to sustainability, ST, and learning come to the front. This indicates that these themes are well studied in the past and recently they lost their centrality. Motor themes in the map appear to reside in two clusters. The first cluster consists of themes like ST, education, higher education, and education for sustainable development. This cluster by itself proves the research interest in education for sustainable development. Themes related to curriculum, green chemistry, first-year undergraduate/general education, and interdisciplinary/multidisciplinary also form another cluster in the motor themes quadrant. Studies related to these themes are both higher in density and centrality, meaning that current and future studies are more focused on these themes. Themes related to medical education and patient safety also form another cluster that is placed on the density axis of the map. This cluster shows the recent interest in studies related to these themes. In the emerging themes quadrant climate change also appears as a recent concern for research, since climate change is a major problem in the 21st century. Studies related to this theme are few but increasing. The cluster of environmental education is placed near the climate change cluster. So, themes related to environmental education can be also seen together with climate change.

Co-Authorship Analysis

Scientific collaboration in contemporary research fields becomes a necessity each day as the complexity of the research field increases with the published articles and the knowledge produced by those articles increases. Increasing specialization needs for each research project and the necessity of bringing together different skills and knowledge together introduce scientific collaboration in and outside of academia as a necessity (Katz & Martin, 1997; Sonnenwald, 2007). In these circumstances, scientific collaboration is best defined as the interaction that takes place between two or more researchers in a social context who shares a common meaning and fulfillment of tasks to accomplish a shared goal (Sonnenwald, 2007). Through scientific collaboration, the scope of the research can be broadened and innovation can be promoted in unpredicted directions (Beaver, 2001).

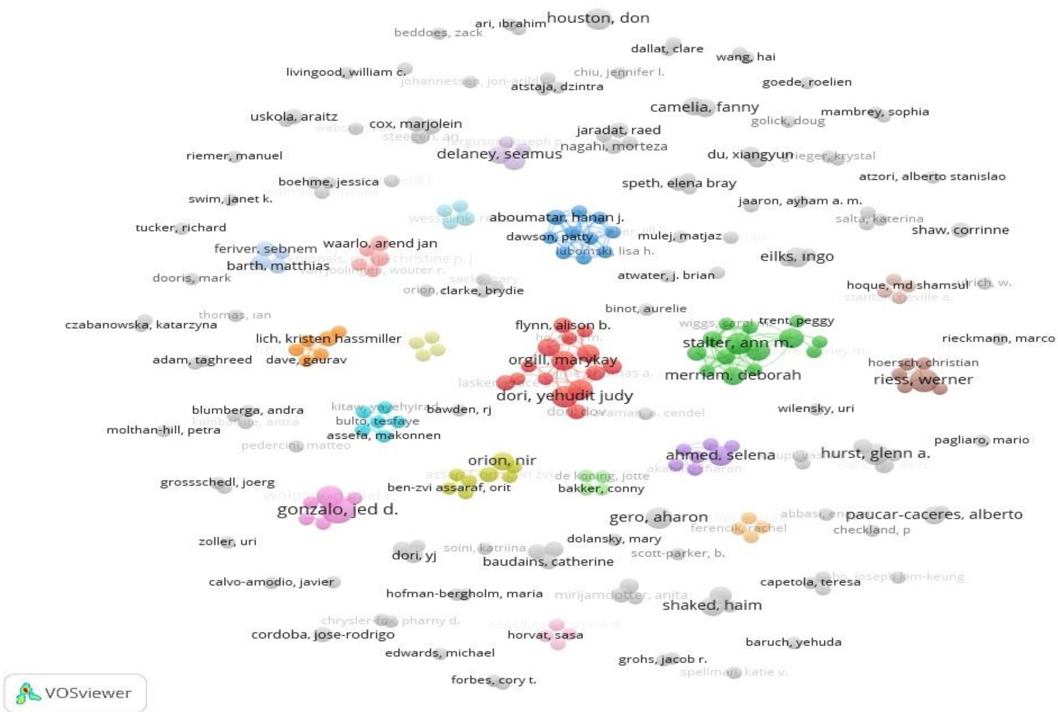

Figure 6. Co-authorship analysis of ST research in education.

In this study to illustrate scientific collaboration, co-authorship analysis in VOSviewer software was utilized to provide collaboration patterns between researchers. The resulting graph of the analysis is shown in Figure 6. As seen in the figure even though the authors do not form an interconnected network and they seem to work in isolated groups. Researchers working in the field of biology are grouped in the brown cluster, researchers working in the field of nursing in the green cluster, and researchers working in the field of science in the yellow cluster. It is seen that there is no interdisciplinary work among these clusters corresponding to different fields. On the other hand, although the orange cluster with Lich and Dave, the dark blue cluster with Aboumatar and Dawson, and the pink cluster with Gonzalo are composed of groups conducting research in the same disciplinary context, that is, in the field of health education, there is no research collaboration between these clusters. The reason behind this seems to be that mainly researchers from the same institution or affiliation prefer to work together.

Co-Citation Analysis

In this study, co-citation analysis was performed using network visualization by VOSviewer software. Co-citation analysis is generally used for analyzing the intellectual background of a research field. In the network diagram, the minimum threshold for the number of citations a cited document receives is set to 10. 156 documents out of the total of 40,817 documents satisfy this condition. These documents were selected to illustrate the network map shown in Figure 7. In the figure, the size of the circles and their labels indicate the importance of the corresponding item in the network. The size of the circles indicates the frequency of citations. Authors that are in the same cluster are more likely to be cited jointly in a given publication. The connection between the two items is expressed as links. Items that have more connections compared to other items form a cluster in the network. An item in the network can only belong to one cluster. Each cluster is colored by a distinct color and the color of the item determines which cluster the item belongs. Also, the degree of co-citation is indicated by the size of the cluster, and the strength of the co-citation connections is shown by the width of connecting lines.

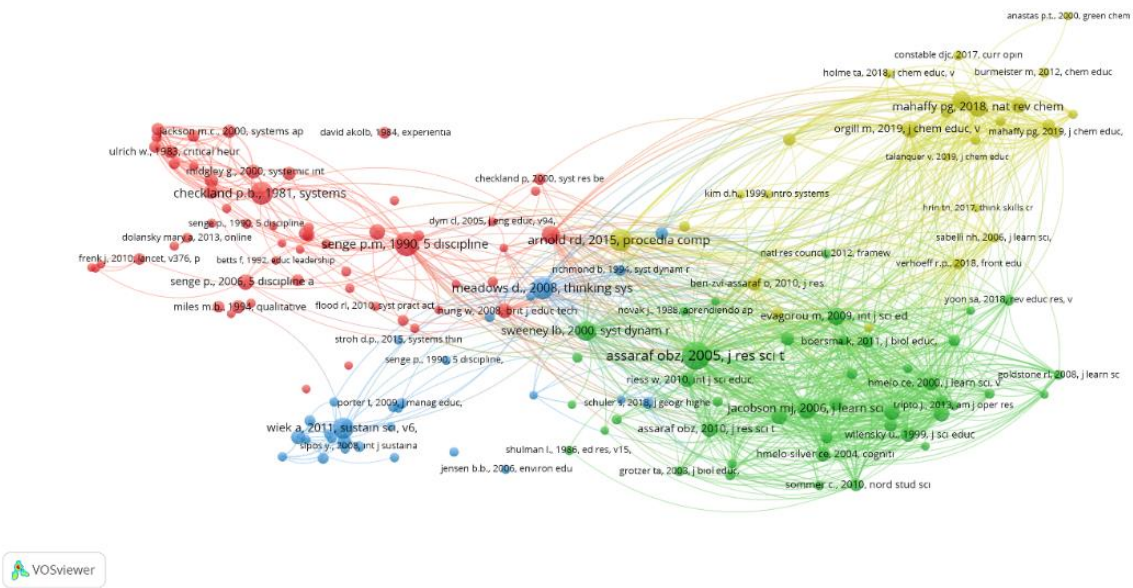

Figure 7. Co-citation analysis of ST research in education.

According to the co-citation graph in the figure above (Figure 7), four main clusters can be seen in ST research in education. The first cluster on the graph is led by Peter Senge and mainly includes authors such as Peter Checkland, Barry Richmond, Ross D. Arnold, and Bela H. Banathy. This cluster includes theoretical studies concerning ST, systems dynamics, systems theory, learning organizations, etc. The second cluster is mostly led by Orit Ben-Zvi Assaraf. Besides Ben-Zvi Assaraf, researchers like Linda Booth Sweeny, Michael J. Jacobson, Cindy E. Hmelo-Silver, and Maria Evaragou are also included in this cluster. The documents found in this cluster are especially important for the studies about science and technology education and related subjects. The third cluster consists of authors like Donella Meadows, Arnim Wiek, and Barry Richmond. These documents are fruitful for education for sustainable development, higher education, and related matters. The fourth cluster is mainly about the documents concerning the use of ST in chemistry education, green chemistry, and related subjects. Researchers like Peter G. Mahaffy, MaryKay Orgill, and Sarah York are prominent in this cluster.

Table 7. Ranking of the top ten authors in co-citation analysis.

Author	Citations	Total Link Strength	Link count	Cluster
Ben-Zvi Assaraf, O.	95	957	135	2
Senge, P.	70	386	130	1
Checkland, P.	64	315	99	1
Arnold, R. D.	62	481	125	4
Meadow, D.	60	415	125	3
Wiek, A.	53	240	85	3
Sweeney, L. B.	48	449	112	2
Mahaffy, P. G.	46	393	80	4
Jacobson, M. J.	43	573	113	2
Richmond, B.	40	312	100	1

The most prominent figures according to the co-citation analysis in ST studies in education are listed in Table 7. Total citations received by each author's document, the total number of links the document has and the strength of the links between the documents, and the cluster the document belongs to are listed in this table. The article by Ben-Zvi Assaraf as the lead author (Ben-Zvi Assaraf & Orion, 2005) received 95 citations from the articles in the dataset. In addition, the article in question was co-cited with 135 articles and cited a sum of 957 times with all these articles and was in the second cluster in the co-citation graph.

Discussion & Conclusion

As emphasized in the introduction section, ST is a subject that becomes important every passing day for the sustainable development of the world. Since UNESCO's 2015 report based on sustainable development goals set by the UN at the start of the 21st century (UN, 2000), education for sustainable development became an important goal for all nations worldwide to accomplish (UNESCO, 2016). ST in this report was defined as the key competency to be acquired by students of all ages. As outlined in the findings the research on ST in education started to increase exponentially after 2015. However, since the beginning of the millennium, a slight increase in the studies on this subject could be observed mainly due to the importance of sustainability received from the UN and its member states.

Most cited articles in ST research in education are either application studies of ST in general educational curricula or the search for integrating ST into various educational curricula, like chemistry, biology, STEM, engineering, etc. In their bibliometric analysis of systems thinking in STEM education, Bielik et al. (2023) emphasized that the published articles are mostly concentrated in the mentioned fields. In line with the findings of the current study, they found that systems thinking is more studied in fields such as chemistry, biology, engineering, etc. The studies that are about general curriculum (Bates, 2012; Ndaruhutse, Jones, & Riggall, 2019; Rieckmann, 2012) are more directed at the discussion of ways to adapt ST to educational matters, or lessons at schools. These kinds of studies signify that ST research in education is at the initial stages of its development and more applications in educational environments or schools will likely be coming soon. For instance, two studies by Ben-Zvi Assaraf and Orion in 2010, "System thinking skills at the elementary school level" and "Developing system thinking skills in junior high school and sustaining them over time", which are among the most cited in this study, showed that although ST is considered as a higher order thinking skill, it can be developed to a certain extent with appropriate activities in elementary and middle schools and that a long-term, well-planned curriculum can be the basis for the development of higher levels of ST at high school level.

A striking finding in performance analysis of the studies in ST in education is that the journals, articles, and authors that have received the most citations are from the fields of science education, like chemistry, medicine, biology, engineering, etc. The only article that does not match this conclusion is by Rieckmann (2012), titled "Future-oriented higher education: Which key competencies should be fostered through university teaching and learning?" Although it was the most globally cited study, Rieckmann's article is not directed at science education. Instead, Rieckmann became influential in studies concerning sustainability. Especially regarding university or higher education curricula, sustainability became an important principle or guide in the last decade. Rieckmann advocated that ST must be one of the key competencies that university students must acquire. In particular, the studies in the dataset that address the use and development of systems thinking in higher education in the context of sustainability (Ateskan & Lane, 2018; Shukla, 2018; Stevens, Whitehead & Singhal, 2022) confirm Rieckmann's argument. Nevertheless, the majority of higher education studies in the dataset are in science and engineering (Kellam, Maher, & Peters, 2008; Michalopoulou et al., 2019; Muljana, Nissenson, & Luo, 2020; Orgill, York, & MacKellar, 2019). Therefore, it can be said that there is a serious gap in the field of studying this topic in social sciences even at the higher education level.

A brilliant example of the application of ST in the field of education, which applied ST to earth-system education with 50 eighth-grader students is a study by Ben-Zvi Assaraf and Orion titled "Development of system thinking skills in the context of earth-system education". The co-citation analysis (Figure 7) shows that this article is central to the intellectual structure of the field and ranks first in terms of most citations, high number of links, and total link strength. In addition, in the bibliometric study by Hossain et al. (2020) aiming to reveal the general structure of systems thinking, in the analysis of frequently co-cited articles, the cluster in which the article by Ben-Zvi Assaraf and Orion (2005) is located is defined as "Development of systems thinking tools and techniques" and it is seen as the only article from the field of education in the top ten list of most co-cited articles. This study can be regarded pioneer in various fields like biology (Momsen, Speth, Wyse, & Long, 2022), chemistry (Szozda, Bruyere, Lee, Mahaffy, & Flynn, 2022), STEM, geography (Mehren & Rempfler, 2022), physiology (Gregorčič & Torkar, 2022), computer technologies (Aguilar-Cisneros, Valerdi, & Sullivan, 2022), human resources (Miller, Kordova, Grinshpoun, & Shoval, 2022), and tourism (Rezapouraghdam & Akhshik, 2021).

Word frequency (see Table 6) and co-occurrence analysis (see Figure 4) provide a general summary of the ST research in education. When words like "systems thinking" and "education" are neglected, various educational concerns where ST comes to the front appear in the most frequently used words' tables. Sustainability, higher education, chemistry, engineering education, medical education, and climate change are striking words in those tables. Bielik et al. (2023), in their bibliometric study on systems thinking research on STEM, analyzed the frequently used words in the articles they reached. According to this analysis, they found that the keywords "thinking", "science", "knowledge", "curriculum", "student", and "chemistry" were the most frequently used words in the articles they reached. It is noted that these words overlap with the frequently used keywords in the current study. In this respect, it can be said that this finding supports the conclusion that science education is predominant in systems thinking research in education.

Hossain et al. (2020), in their bibliometric study of research on systems thinking in general, report that keywords such as "sustainability", "sustainable development", "education", "leadership", "thinking", "learning" are the most frequent words in used in the studies on ST. This result overlaps with the frequently used keywords in the current study. Therefore, it can be said that the character of scientific studies on systems thinking is also reflected in educational research. In other words, educational research follows systems thinking studies on a general scale. Especially sustainability is a key term in paving the way for ST research in general. Sustainability as a motive for UNESCO's declaration for Education for Sustainable Development in 2015, is a driving force for the research of key competencies like ST (Schuler et al., 2018). This situation is supported by the studies in Higher Education for Sustainable Development (HESD) for formulating a curriculum to enhance key competencies for sustainability, like systems thinking, anticipatory thinking, and critical thinking (Qadhi & Al-Thani, 2023; Wu & Shen, 2016). Studies regarding the formulation of the curriculum in higher education (Davis, Dent, & Wharff, 2015; Dhukaram, Sgouropoulou, Feldman, & Amini, 2018; Dunnion & O'Donovan, 2014; Grohs, Kirk, Soledad, & Knight, 2018) may highlight a similar trend in fields related to science education. As mentioned before ST research in fields like chemistry or biology, are at the initial stages where discussions about curriculum are more important. Therefore, the prior aim of these studies is to adapt or apply ST to educational purposes.

The major global problems in the 21st century, like climate change, pollution, insufficiency of resources, etc. bring out sustainability as an urgent agenda for the world population. From the bibliometric analysis established in the study, it could be said that ST as a key competency to accomplish the goals of sustainable development, has been effectively studied in science education research (Davila, Plant, & Jacobs, 2021; Mahaffy, Matlin, Whalen, & Holme, 2019; Yakymenko, Poplavko, & Lavrysh, 2020; York & Orgill, 2020). However, research concerning ST in social science education does not demonstrate a parallel outcome. When most cited journals, articles, and authors found in this study are observed studies concerning social science education are also found to be insufficient.

The fact that educational research consists of different disciplines with a wide context can be stated as the main reason why the authors in the field do not have a mutual collaborative working network. In each discipline, there is a collaboration that forms a single group and thus each discipline has its pioneers instead of general influencers. Therefore, it can be interpreted that education is a wide field that includes many disciplines. Co-citation analysis also supports this situation. Although authors from different fields do not carry out collaborative works, they cite each other's works and thus forming a different kind of network of collaboration.

The theoretical background of ST in education is rooted in intellectual studies from the 1950s to the 2000s. In this regard, theoretical work by Forrester (1958), Churchman (1968), Von Bertalanffy (1968), Ulrich (1983), Jackson (1991), Richmond (1993), and Senge (1994) should be mentioned. Besides these, recent studies by Arnold and Wade (2015), Ben-Zvi Assaraf and Orion (2005), Mahaffy, Krief, Hopf, Mehta, and Matlin (2018), Orgill et al. (2019), Sweeney and Sterman (2000) and Wiek, Withycombe, and Redman (2011) which concentrated on how to apply ST to different disciplines of education can be said to contribute new thinking schools in the research field.

Historical evolution of the research field indicates that until 2015 concepts or topics like critical system thinking, complexity, systems theory, and organizational change have been studied the most. From 2015 on, studies on concepts like leadership, and especially higher education and engineering gained momentum. After UNESCO’s 2015 declaration of education for sustainable development, concepts related to sustainability become strikingly dominant in the research field. In different disciplines of education, like chemistry, biology, and medicine, ST research in education becomes evident. In the last three years of the analyzed interval, concepts like sustainable development goals, green chemistry, and STEM is seen to be significant.

As a conclusion of the bibliometric analysis, it could be emphasized that ST as a key competency for sustainable development is a lively topic for the field of education research. In especially science education and related fields ST has been studied extensively in recent years. The number of publications each year supports this conclusion. The foremost reason for this interest in ST research in education can be pointed out as the progress brought out by various declarations by the UN and UNESCO concerning Education for Sustainable Development.

Limitations and Recommendations

In the study, performance analysis, which helps to reveal the descriptive characteristics of the literature, annual scientific production, trending topics and most used words, and important themes in the field, was conducted with RStudio and Biblioshiny programs. Science mapping analysis, which reveals the relationships of key concepts, citations, and authors through visual mapping, was performed with the VOSviewer program. Therefore, two different statistical platforms were used in the study, providing diversity in terms of the tools used in the analysis. Thus, it was ensured that hundreds of data in the field were analyzed simultaneously and the results obtained were better presented both statistically and through visual mapping of the relationships between concepts. Therefore, the current research makes an important contribution to the literature in terms of revealing the general situation of ST in education, and the intellectual and conceptual structure of the field with the help of bibliometric analysis and visual maps. In this way, other researchers in the field are provided with a general perspective on what kind of studies are prominent, the structure of the field, and social network interactions. On the other hand, since the preferred bibliometric analysis method provides a statistical and general perspective, it is not possible to look at the content of each study on ST in education and its contribution to society and the field.

This study is limited to journals indexed in the WoS database. In future similar studies, it may be recommended to consult different databases such as Scopus and ERIC. Researchers are recommended to conduct research on ST in different disciplines of education such as various fields of social sciences (history, geography, philosophy, language teaching, etc.). Also, in general, it is recommended to narrow the research focus and conduct studies such as content analysis or systematic reviews that reveal the social contribution of ST. Finally, it is hoped that this study will provide a guide for researchers who are interested in conducting research on ST in education.

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