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The landscape of complexity science in education: A scoping review of peer-reviewed articles

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Abstract

This study aims to explore how complexity science has been applied in education and to identify key research patterns, with a particular focus on the role of systems thinking as one of its central educational manifestations. Using a combined approach of bibliometric mapping, content analysis and thematic synthesis, the study analyses 357 publications from 2015 to 2024 alongside 50 influential articles selected for in-depth review. Findings reveal that while complexity science provides a strong theoretical foundation for understanding dynamic and adaptive learning environments, its translation into educational practice remains partial. Systems thinking emerges as a major theme, especially in studies involving K–12 and undergraduate students, highlighting interest in fostering holistic and interdisciplinary perspectives. However, teachers and administrators are less frequently studied, pointing to an important gap in practice-oriented research. Data collection is dominated by traditional surveys and tests, though qualitative and multimodal approaches are gaining visibility. The analysis identifies five thematic dimensions: applications across contexts, impacts on student learning, theoretical grounding, implementation strategies and challenges. Overall, the field shows steady growth yet limited integration across disciplines and regions. The study concludes that advancing complexity-informed education requires stronger methodological diversity, greater attention to educators' roles and enhanced international collaboration.

KEYWORDS
bibliometric analysis, complex systems, complexity science in education, non-linear dynamics, scoping review, self-organization, systems thinking, thematic analysis

Practitioner notes

What is already known about this topic

- Complexity science provides a rich theoretical framework for understanding learning as a dynamic, adaptive and context-sensitive process.
- Systems thinking is increasingly promoted as a key 21st-century competency, particularly in STEM and sustainability education.
- Despite its theoretical appeal, the integration of complexity-based approaches into empirical educational research and everyday classroom practice remains limited, with teachers and administrators underrepresented in existing studies.

What this paper adds

- This review synthesizes findings from 357 publications and 50 high-impact studies to provide a comprehensive map of how complexity science is applied in education.
- It identifies five major thematic domains, including applications of systems thinking, its cognitive and socio-emotional benefits and implementation strategies.
- The study highlights methodological gaps (e.g. reliance on traditional survey tools, limited mixed methods use) and underscores the need for broader international collaboration.
- It reveals a growing but uneven shift from conceptual work towards practice-based and interdisciplinary applications, with chemistry and environmental education leading in experimental designs.

Implications for practice and/or policy

- Teachers and instructional designers can use systems thinking tools (e.g. causal-loop diagrams, scenario-based modelling) to support higher-order thinking and collaborative learning.
- Teacher education and professional development programs should explicitly incorporate complexity-informed pedagogies.
- Policymakers should address systemic barriers such as curricular constraints and teacher preparedness, while fostering global and cross-disciplinary collaborations.
- Educational policy and curriculum development should prioritize systemic thinking skills and foster environments where adaptive, interdisciplinary and inclusive learning can thrive.

INTRODUCTION

Complexity science has emerged as a powerful interdisciplinary framework for understanding dynamic, adaptive and often unpredictable systems across a wide range of fields, including biology, ecology, computer science, economics and organizational studies (Byrne & Callaghan, 2013; Mitchell, 2011). The complexity perspective centres on multifaceted, multidirectional and evolving interactions among individual components, closely aligning with the core principles of systems thinking (Boersma et al., 2011; Davis & Sumura, 2006; Jacobson & Wilensky, 2006). These systems are characterized by non-linearity, self-organization, feedback loops and historical sensitivity. Rather than relying on deterministic assumptions, complexity-based approaches emphasize uncertainty, emergence and contextual dynamics.

This perspective is particularly relevant for the integration of systems thinking in education, as it promotes understanding of complex problems by focusing on the components, their interrelations and the consequences of their interaction (Arnold & Wade, 2015). Complexity science provides a valuable lens for rethinking teaching and learning processes in educational research (Davis & Sumura, 2006; Thelen & Smith, 1994). While traditional models are often based on linear cause-and-effect relations and isolated interventions, complexity-oriented approaches conceptualize education as a multi-level system of interacting learners, teachers, technologies, institutions and sociocultural contexts (Jacobson et al., 2019). In this system, learning emerges through interactions and is shaped by prior knowledge, motivation, emotions, peer dynamics and technological mediators. As such, educational outcomes are not merely the sum of isolated variables but the emergent features of evolving systems.

In this context, there is increasing interest in applying complexity-informed approaches to better understand the multidimensional, interactive and evolving nature of educational processes. Particularly in science education, such frameworks are valuable for analysing large-scale phenomena such as climate change, ecosystems and population dynamics. Jacobson and Wilensky (2006) argue that to help students develop reasoning about complex systems, educational interventions should support systems-level and agent-based thinking. Instructional strategies designed to foster such skills often involve recognizing feedback structures, identifying delays and interpreting emergent behaviours (Boersma et al., 2011; Sweeney & Sterman, 2007).

For example, Fisher and Systems Thinking Association (2023) emphasize the cognitive benefits of scenario-based activities that help students analyse environmental issues from a systemic perspective. Similarly, Brychkov et al. (2024) show that collaborative digital tools used in sustainability education support the development of system boundary identification and actor recognition skills. Gilissen et al. (2020) report that while students often struggle to understand hierarchical structures and dynamic processes in biology classes, they show improved comprehension of systemic relationships when using visual metaphors and interactive activities. Leisner et al. (2023) examine the pedagogical and institutional constraints that teachers face when developing systems thinking competencies, highlighting the challenges to mainstreaming system-based instruction. Despite such examples, integration of systems thinking into educational practice remains limited (Ford, 2019; Gilissen et al., 2020).

Beyond practical challenges, theoretical diversity also hinders coherence in the field. Studies in complexity-informed education draw from various traditions such as general systems theory, cybernetics, dynamic systems theory, sociocultural theory and education for sustainable development (Boersma et al., 2011; Jackson, 2019). Although this richness encourages flexibility and innovation, it also creates conceptual ambiguity and complicates comparison across studies. When combined with methodological limitations, this diversity constrains the field's institutional representation and sustainable development (Kopnina & Meijers, 2014; Parry & Metzger, 2023; Shephard, 2023). Fragmentation of focus—whether on knowledge and learning or collaboration networks and curriculum structures—limits systematic knowledge building (Pekrun, 2024; Santos et al., 2017).

Meanwhile, the rise of digital learning environments introduces new layers of complexity. Online platforms, learning analytics and AI-supported systems form dynamic, data-rich ecosystems involving human and algorithmic agents. Learning behaviours are shaped not only by social and instructional factors but also by algorithms, recommendation engines and adaptive feedback tools. Rojas and Chiappe (2024) argue that current educational technology models fall short in capturing the emergent, self-organizing and non-linear nature of such digital ecosystems. Similarly, Sajja et al. (2025) highlight the need for decision-making frameworks aligned with complexity to support meaningful learning in these environments.

Given these intersecting issues, a comprehensive synthesis that bridges theoretical and empirical developments in the field is necessary. While various narrative reviews and conceptual discussions exist, no systematic review has holistically examined complexity science and education through theoretical frameworks, methodological designs and empirical applications. Existing reviews tend to focus narrowly—on sustainability education, science curricula or cognitive models—and fall short in offering broad insights to guide future research agendas (Leisner et al., 2023). Nogueira (2023) underscores the methodological fragmentation and lack of maturity in complexity-informed research in education.

To address this gap, this study presents a comprehensive review of empirical peer-reviewed studies published between 2015 and 2024. Following Arksey and O'Malley (2005) framework, this study adopts a scoping review design, aiming to map and describe the scope and characteristics of existing research. Based on this framework, it adopts a qualitatively oriented embedded mixed methods design, integrating bibliometric mapping, content analysis and thematic synthesis. Bibliometric analysis reveals publication trends, leading authors and collaboration patterns (Aria & Cuccurullo, 2017; Donthu et al., 2021). Content analysis investigates how complexity-related concepts and methods are implemented in practice, while thematic analysis explores themes and conceptual patterns aligned with principles of complexity science (Durak et al., 2018; Elo & Kyngäs, 2008; White & Marsh, 2006). This methodological design reflects the multidimensional nature of the field and aims to capture both its surface structure and deeper conceptual fabric. The study provides a layered portrait of the field's evolution, offering insights for researchers, educators and policymakers seeking to understand and engage with complexity-informed educational research.

Accordingly, the study is guided by the following research questions:

- Which theoretical frameworks, research methodologies and data collection instruments are most commonly employed in studies on complexity science in education?
- What key themes emerge from the literature, and how do they align with the core principles of complexity science?
- What are the publication trends, influential contributors and collaboration networks in the literature on complexity science in education?

METHOD

This study adopts a qualitatively oriented embedded mixed methods design (Creswell & Plano Clark, 2018; Plano Clark & Ivankova, 2016), combining bibliometric techniques, qualitative content analysis and thematic synthesis to examine how complexity science is conceptualized and applied in educational research. This design enables a comprehensive exploration of both the structural development and conceptual depth of the field, addressing the needs for both descriptive mapping and interpretive insight (Aria & Cuccurullo, 2017; Donthu et al., 2021).

Data collection and inclusion criteria

Following recommendations by Costa et al. (2023) and guided by the PRISMA 2020 framework (Page et al., 2021), a systematic search strategy was implemented using the Web of Science (WoS) database. WoS was chosen due to its comprehensive coverage of peer-reviewed and high-impact academic journals, as well as its compatibility with bibliometric tools such as VOSviewer (v1.6.19) and Bibliometrix R packages (Aria & Cuccurullo, 2017). A graphical summary of this systematic search and selection process is presented in Figure 1.

The keyword combinations were constructed around core terms related to complexity science and education. Keywords included: *'complexity science'*, *'complex systems'*, *'non-linear dynamics'*, *'emergence'*, *'self-organization'*, *'adaptation'*, *'systems thinking'*, combined with terms like *'education'*, *'learning'*, *'teaching'*, *'instructional design'*, *'online learning'* and *'learning environments'*.

Boolean operators (AND/OR) were used to optimize the search results. The inclusion criteria were:

- Articles published between 2015 and 2024,
- Peer-reviewed journal articles,
- Studies with a clear application or conceptual discussion of complexity science within educational contexts.

Studies that mentioned complexity science only in passing or in unrelated domains (e.g. engineering or healthcare without educational relevance) were excluded. Three researchers independently reviewed the abstracts and full texts for eligibility, and discrepancies were resolved through discussion. The final dataset included 357 articles, which formed the basis for both bibliometric and qualitative analysis stages.

Descriptive publication trends

Before delving into the content and thematic analyses, the general publication trends across the dataset are presented. Figure 2 illustrates the annual distribution of the 357 articles included in the study.

As shown in Figure 2, the number of studies steadily increased from 2015, peaking in 2019 and again in 2024. This pattern reflects the rising interest in complexity-oriented educational research, driven by evolving pedagogical paradigms, online learning and sustainability-focused frameworks.

Data analysis

This study adopted an integrated approach, combining bibliometric, content and thematic analysis to systematically explore the application of complexity science in education. This multi-method framework enabled both a macro-level mapping of the field's intellectual landscape and a micro-level investigation of thematic and methodological patterns.

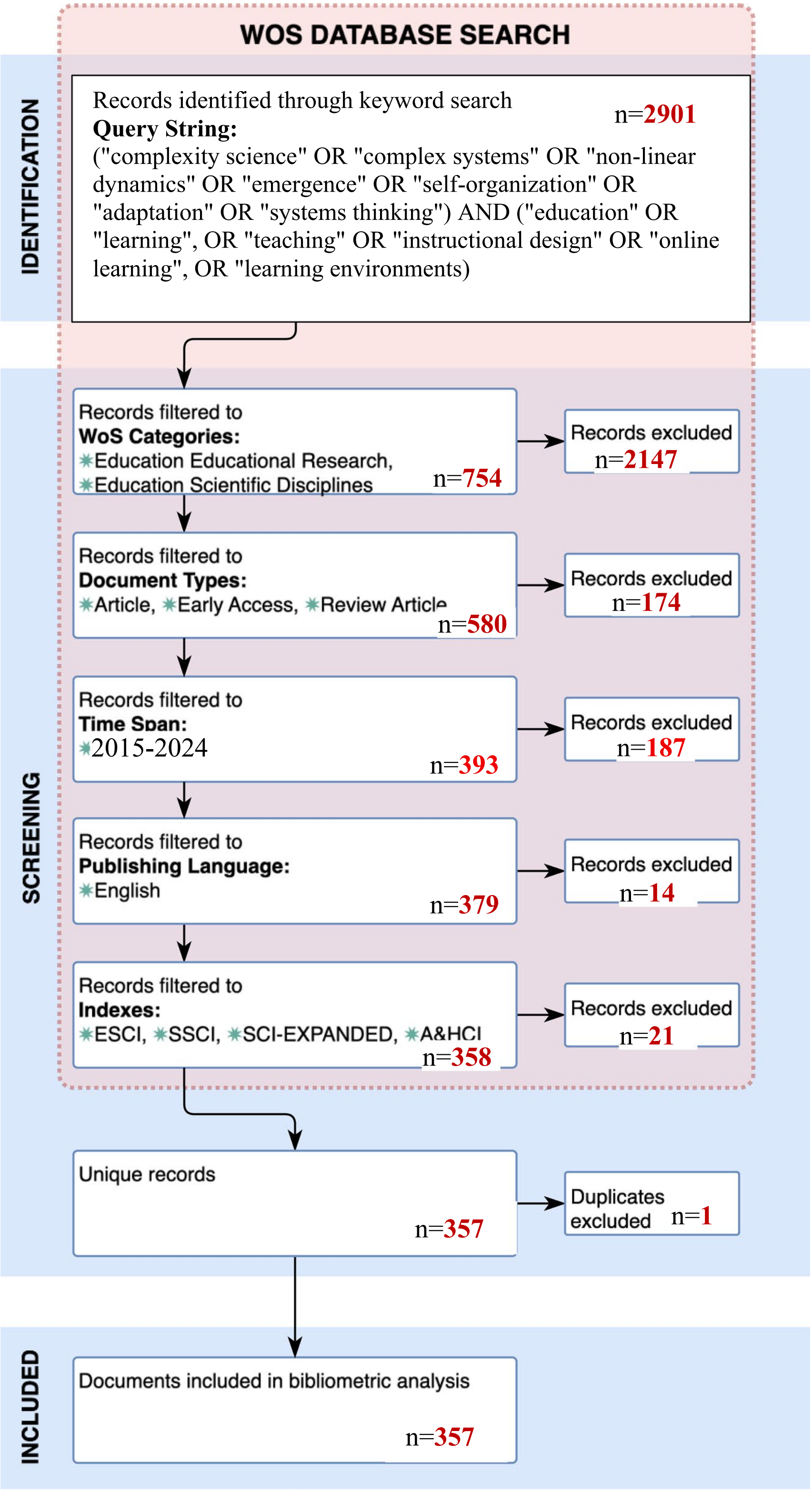

FIGURE 1 PRISMA flowchart for outlining the procedures of the bibliometric analysis in this study.

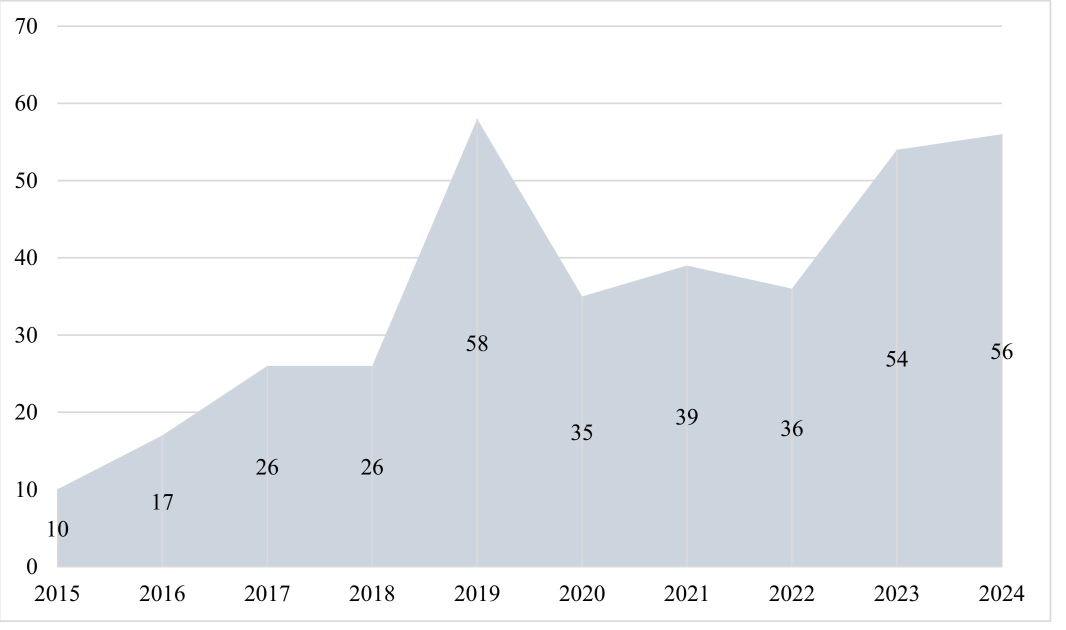

FIGURE 2 Number of publications by year.

Bibliometric analysis

Bibliometric analysis was conducted using VOSviewer and Bibliometrix in R to generate visual and statistical insights into the intellectual structure of the field. Five bibliometric techniques were used:

- **Citation analysis**—to identify the most influential articles, authors and journals.
- **Co-citation analysis**—to uncover foundational clusters in the literature.
- **Co-authorship analysis**—to map collaboration networks among scholars and institutions.
- **Keyword co-occurrence analysis**—to reveal thematic patterns and conceptual associations
- **Trend analysis**—to trace the temporal development of research interests over the past decade.

Content and thematic analysis

The qualitative phase focused on a purposive subsample of 50 articles, selected solely based on citation impact. Specifically, the selection included the top 10 most-cited publications from each year between 2020 and 2024. This strategy ensured both recency and scholarly impact, allowing the analysis to focus on studies with demonstrable influence (Tahamtan et al., 2016).

A coding framework was developed based on prior research (Elo & Kyngäs, 2008; Erlingsson & Brysiewicz, 2017). Key coding categories included:

- Theoretical framework(s)
- Research design and methodology
- Data collection instruments

- Educational level and context
- Operationalization of complexity concepts (e.g. emergence, feedback loops)

Three researchers coded the 50 articles independently. Inter-coder reliability was calculated using Cohen's kappa ($\kappa = 0.94$), indicating excellent agreement (Strijbos et al., 2006). Discrepancies were discussed until consensus was reached.

In parallel, thematic synthesis was employed to identify recurring motifs, conceptual tensions and application patterns. This process involved:

1. Iterative reading and open coding.
2. Grouping codes into conceptual categories.
3. Synthesizing themes aligned with core principles of complexity science (e.g. non-linearity, adaptation, self-organization)
4. Cross-validating themes across different educational levels and methodological designs

Themes were continuously refined and validated against full-text data to ensure coherence and depth. This process supports a deeper understanding of how complexity concepts are embedded in educational research and offers practical insights for the design and improvement of dynamic learning environments.

Findings

The findings are organized around the research questions, beginning with content analysis, followed by thematic insights and concluding with a bibliometric overview of the field.

RQ1: Content analysis

This section explores trends in research methods, participants, data collection tools, variables and theoretical frameworks. It draws on a targeted subset of the 357 publications identified via bibliometric procedures, focusing on the top 10 most-cited studies from each year between 2020 and 2024 ($N = 50$). This approach ensures recentness and relevance while avoiding sampling bias towards older publications.

Participants

The reviewed studies featured diverse participant groups across formal and informal educational settings. Table 1 summarizes the frequency and sample size ranges of participant types.

According to Table 1, undergraduate students were the most commonly studied group, followed by K-12 students. These two groups accounted for nearly half of all empirical studies, reflecting a strong interest in how complexity principles manifest in formal education. Teachers and academic staff were also studied but less frequently. This imbalance suggests a potential research gap regarding educators' roles in enacting or navigating complexity.

Data collection tools

A wide array of data collection tools was used, spanning both qualitative and quantitative traditions. Table 2 provides a breakdown.

TABLE 1 Participant descriptions of included studies.

Participants	Frequency	Range of sample size
Undergraduate students	13	15–418
K12 students	10	18–7178
Teachers	6	8–56
Academics and staff	4	14–45
K12 administrators	3	5–11
Other	2	–

Note: Some studies did not involve human participants (e.g. conceptual or theoretical analyses), which explains the lower total frequency count.

TABLE 2 Data collection tools.

Data collection tools	Frequency
Questionnaires/Surveys	21
Achievement tests	17
Interviews	13
Observations	9
Assessments	8
Reflection notes	5
Video/audio records	5
Portfolios	3
Document analysis	3
Other	6

Note: One study may employ more than one data collection tool.

According to Table 2, Questionnaires/surveys were the most frequently used tools (21 studies), emphasizing perception-based inquiry and learner experiences. Achievement tests (17) highlighted focus on cognitive outcomes, while interviews (13), observations (9) and reflection notes (5) provided deeper qualitative insights. Multimodal data collection was evident in several studies, combining tools to triangulate findings.

Variables/research interests

The articles were analysed based on their dependent variables and focal research interests. Table 3 shows the corresponding frequencies. It was observed that some studies had multiple dependent variables, while others had none.

Systems thinking skills emerged as the most frequently examined variable, underscoring the centrality of this concept within complexity-informed education. Academic outcomes followed, while variables such as literacy level and ability received less attention. Notably, a significant portion of studies included context-specific or emergent constructs under the 'Other' category, such as learning confidence, enjoyment, engagement and communication skills, highlighting the evolving and interdisciplinary nature of this research area.

Research methods and designs

The studies utilized a variety of research methods and designs, as outlined in Table 4. These were further classified into empirical, conceptual and practice-based orientations.

TABLE 3 Variables/research interests.

Variables	Frequency
Systems thinking skills	11
Academic outcome	8
Literacy level	4
Ability	3
Other	12

Note: One study may employ more than one variable.

TABLE 4 Frequencies of methods and models/designs.

Research methods	*f*	Research designs/models	*f*
Quantitative	10	Experimental	7
		Survey	2
		Correlational	1
Qualitative	12	Case study	11
		Content analysis	1
Mixed/Triangulation	7	Convergent parallel	6
		Explanatory sequential	1
Other/Theoretical/Descriptive	16	Position paper	10
		Systematic review	3
		Reflection paper	1
		Report	1
		Technical paper	1
Network analytics/Digital/Innovative	1	Learning analytics	1
Practice Based	5	Design-based research	4
		Action research	1

Note: One study may employ more than one research design/model.

According to Table 4, qualitative methods were most common (12 studies), particularly case study designs (11), suggesting a preference for in-depth, context-rich analysis. Quantitative methods (10) frequently employed experimental or quasi-experimental designs, often in controlled learning environments. Mixed methods (7) demonstrated an interest in combining numerical data with narrative depth. A notable portion of studies (16) were theoretical, reflective or review-based, indicating the field's strong conceptual foundation. Practice-based studies—such as design-based or action research—also contributed valuable insights into how complexity principles are applied in real-world educational innovations.

Theoretical frameworks

A wide spectrum of theoretical frameworks was employed, reflecting the interdisciplinary roots of complexity science. The frameworks were grouped thematically, and those cited only once were classified under the *Other* category (Table 5).

Systems Thinking frameworks—including the Iceberg Model and Mehren's model—were the most frequently used, followed by Complexity Theory and General Systems Theory. These frameworks provided conceptual scaffolding to understand dynamic relationships,

TABLE 5 Theoretical frameworks grouped by theme and frequency.

Theoretical framework group	Frequency
Systems thinking (general & named models)	15
Complexity theory/complex systems	10
Ecological systems theory	3
Social constructivism & sociocultural theory	3
Emergence theory	2
Education for sustainable development	2
Green chemistry principles/ChEMIST table	2
Community of practice/inquiry	2
General systems theory	2
Other	28

Note: Some studies employed more than one theoretical framework, while others did not explicitly state any framework.

feedback loops and emergent behaviours in learning systems. Social constructivist and ecological theories offered complementary perspectives on context and interaction. The 'Other' category featured a rich mix of domain-specific models, such as those from chemistry education, sustainability or digital learning, indicating the adaptability of complexity science across domains.

RQ2: Thematic analysis

To address RQ2, a thematic analysis was conducted on the same purposively selected subset of 50 articles identified by citation impact, drawn from the full corpus of 357 studies. The goal of this analysis was to capture how complexity science has been conceptualized, operationalized and examined within diverse educational contexts through the most-cited publications between 2020 and 2024.

Themes were developed through iterative coding and refined collaboratively across the research team. Each article was examined to identify underlying theoretical positions, practical implementations and reported outcomes related to systems thinking and complexity science. Thematic saturation was achieved across five major themes, which together reflect the multidimensional nature of this field.

The following thematic structure is organized progressively: it begins with the foundational applications of systems thinking, moves to its observed impacts on student development, then explores key theoretical underpinnings, followed by practical implementations in diverse educational settings, and concludes with limitations and forward-looking suggestions. Each theme includes illustrative examples to reflect the scope and diversity of this evolving research landscape.

Applications of systems thinking in education

A central theme emerging from the data is the practical integration of systems thinking into educational contexts. These studies highlight how complexity-aligned strategies are implemented through pedagogical tools, interdisciplinary projects and learning technologies. Liang et al. (2024) designed an interdisciplinary project where science teacher candidates visualized climate change and developed both cognitive and social responsibility skills. In higher education, Brychkov et al. (2024) introduced the Connect the Circle tool, which enhanced students' ability to analyse systemic relationships and shift from linear to multidimensional thinking.

Dever et al. (2023) illustrated how AI-supported instructional systems scaffold systems thinking through personalized learning pathways. At the K–12 level, Yoon et al. (2018) emphasized that while younger students naturally attempt systemic reasoning, structured and developmentally appropriate environments are necessary for meaningful learning outcomes.

Taken together, these studies demonstrate that systems thinking acts as a transformative lens—fostering holistic understanding, critical thinking and adaptive learning strategies across disciplines. This foundational integration of systems thinking naturally invites further investigation into how such approaches shape learners themselves, particularly in terms of cognitive, emotional and social development.

Impact of systems thinking on student development

A second key theme centres on the cognitive, emotional and social development of learners exposed to complexity-oriented practices. Demssie et al. (2023) found that students engaged in sustainability projects developed the ability to analyse not just outcomes, but also the dynamic processes behind them.

In primary education, Mambrey et al. (2020) showed that systems thinking instruction helped students understand ecosystems as interconnected systems, rather than isolated facts Liu (2023) reported that university students, through scenario-based climate education, adopted more interactive reasoning patterns when tackling complex issues.

Nieminen and Pesonen (2022) demonstrated that systems-based pedagogy fosters inclusive learning, especially for students with disabilities, by promoting empathy, collaboration and social awareness. This theme reinforces the role of systems thinking in nurturing 21st-century competencies—such as causal reasoning, ethical reflection and collective agency—that are vital for navigating complex societal and environmental issues. To further understand how such competencies are conceptualized and supported, it is essential to explore the theoretical foundations and frameworks that inform systems thinking in educational contexts.

Theoretical foundations and conceptual approaches

Recent studies frame systems thinking not merely as a teaching tool, but as a comprehensive theoretical lens for understanding education. Core theories such as complexity theory, ecological systems theory, dynamic systems theory and connectivism frequently underpin this approach. Batt et al. (2021) illustrated how combining Bronfenbrenner's ecological model with complexity theory supports competency development across system levels. Kaplan and Garner (2020) advocated for a dynamic systems perspective over traditional linear models, emphasizing learning as an evolving, interactive process. Similarly, Saqr and López-Pernas (2024) mapped self-regulation over time, highlighting the relevance of systems thinking in capturing learner variability. Shin et al. (2022) linked systems and computational thinking to help students grasp abstract concepts, while Chaaban et al. (2024) used a systems lens to evaluate how adaptive capacities develop in professional development contexts—at both individual and institutional scales.

This theme emphasizes that systems thinking serves as a unifying conceptual foundation for studying complex educational phenomena. It enables researchers and educators to design interventions that address multi-level dynamics, contextual variability and continuous development. Building on these conceptual foundations, the next theme focuses on how systems thinking is operationalized across various learning environments, translating theory into practice through diverse pedagogical strategies.

Implementation in practice and learning environments

This theme focuses on the operationalization of systems thinking in classroom and institutional settings. Studies in this cluster apply systems-based reasoning across sustainability education, science curricula and digital learning platforms. Demssie et al. (2023) used fieldwork and group projects in sustainability education, enabling students to evaluate environmental, social and economic variables simultaneously. Liang et al. (2024) had teacher candidates map climate change systems, fostering a deeper understanding of causal relationships. Liu (2023) showed that students analysing climate scenarios developed both analytical and ethical dimensions of systemic reasoning. In biology, Momsen et al. (2022) emphasized systems thinking's role in conceptual learning by helping students recognize organismal interconnections. Reynders et al. (2023) applied systems-based modelling in chemistry education to make abstract concepts more concrete. Beyond science, Zhong et al. (2024) examined how esports can be systemically integrated into curricula to enhance collaboration, digital literacy and interaction. These studies highlight that systems thinking is not only a theoretical construct but also a practical, transformative approach. Its integration promotes deeper learning, critical analysis and the ability to engage with complexity—preparing learners for real-world challenges across domains. Having examined its implementation across educational settings, the final theme turns to a critical evaluation—highlighting both the pedagogical benefits and the limitations of systems thinking, while outlining directions for future research and practice.

Benefits, limitations and future directions

The final theme synthesizes the affordances and challenges of implementing systems thinking, while pointing towards future research and practice. Benefits include deeper conceptual understanding, improved engagement and enhanced problem-solving. Batt et al. (2021) showed that systems-based frameworks in health education foster holistic, student-centred learning from individual to societal levels. Demssie et al. (2023) observed high engagement and growth in conceptual and causal reasoning through systems-based activities.

Yet, challenges remain—particularly in K–12 settings. Yoon et al. (2018) stressed the need for age-appropriate materials, teacher preparation and curriculum adjustments. Liang et al. (2024) noted that teacher candidates struggled with conceptual complexity and required guidance. Similarly, Brychkov et al. (2024) found that tools like Connect the Circle are effective but demand substantial educator training.

Future directions point to integrating systems thinking with digital and interdisciplinary methods. Dever et al. (2023) and Zhong et al. (2024) suggest combining it with AI, AR and game-based learning to boost engagement and understanding. Moreover, systems thinking is increasingly viewed as a framework for ethical awareness, equity and sustainability. For example, Nieminen and Pesonen (2022) demonstrated how systems-based, anti-ableist pedagogy enhances inclusivity in higher education. This theme emphasizes that realizing the full potential of systems thinking requires systemic teacher education and learning design. When supported appropriately, it can transform education for the complexities of the 21st century.

RQ3: Bibliometric analysis

This bibliometric analysis includes 357 publications on complexity science in education (2015–2024), drawn from 152 sources and authored by 969 scholars. With an average of 3.2 co-authors per paper, the field reflects strong interdisciplinary collaboration; 18% involved international teams, while 56 were single-authored, showing room for both collaborative and individual contributions. The corpus cites over 15,000 references, with an average of 12.85 citations per document and 1023 unique keywords—indicating conceptual diversity. The average document age is 4.46 years. Over the decade, the number of publications has shown a gradual increase, especially after 2018, reflecting a growing interest in complexity-informed educational research (see Figure 2).

Leading countries and institutions

Figure 3 and Table 6 show that research on complexity science in education is largely led by Anglo-Saxon countries. The USA dominates the field with 307 publications and 2183 citations, highlighting its central influence. The UK (86 publications), Canada (70) and Australia (59) also contribute significantly. This may be associated with their long-standing investment in progressive educational models, the learning sciences and interdisciplinary research cultures that might have contributed to the development of complexity-informed educational inquiry.

Leading journals, institutions and authors

Figure 4 below presents the distribution of publications on complexity science in education across journals and the corresponding number of citations these publications have received. The left chart shows the frequency of articles published in each journal, while the right chart highlights the citation numbers of these journals.

The analysis indicates that the Journal of Chemical Education (JCE) is the most prolific journal, publishing 55 articles on the topic. Other notable contributors include Frontiers in Education (18 articles), Education Sciences (11 articles) and TechTrends (9 articles). In terms of citations, JCEalso leads significantly with 762 citations, followed by Journal of Research in Science Teaching (365 citations) and International Journal of Science Education (326 citations), indicating their strong scholarly influence within the domain of complexity science and education.

Figure 5 displays the number of publications produced by the leading institutions contributing to the field.

The Technion—Israel Institute of Technology leads institutional contributions with 19 publications, followed by the University of Sydney (15) and Bar-Ilan University and Deakin University (11 publications each). These institutions demonstrate sustained interest in complexity-informed educational research.

Figure 6 highlights the most influential authors in terms of citation impact and total citations per year.

The article by Orgill et al. (2019) in JCE leads with the highest total citations and the strongest average citations per year, underscoring its significant and ongoing influence in the field. Hilpert and Marchand (2018) and Berland and Wilensky (2015) follow closely, each contributing notably to the discourse with substantial total citation counts. Additionally, the works of Valantine et al. (2016) and York et al. (2019) also show strong academic interest, indicating their role in shaping key discussions around complexity science applications in science education.

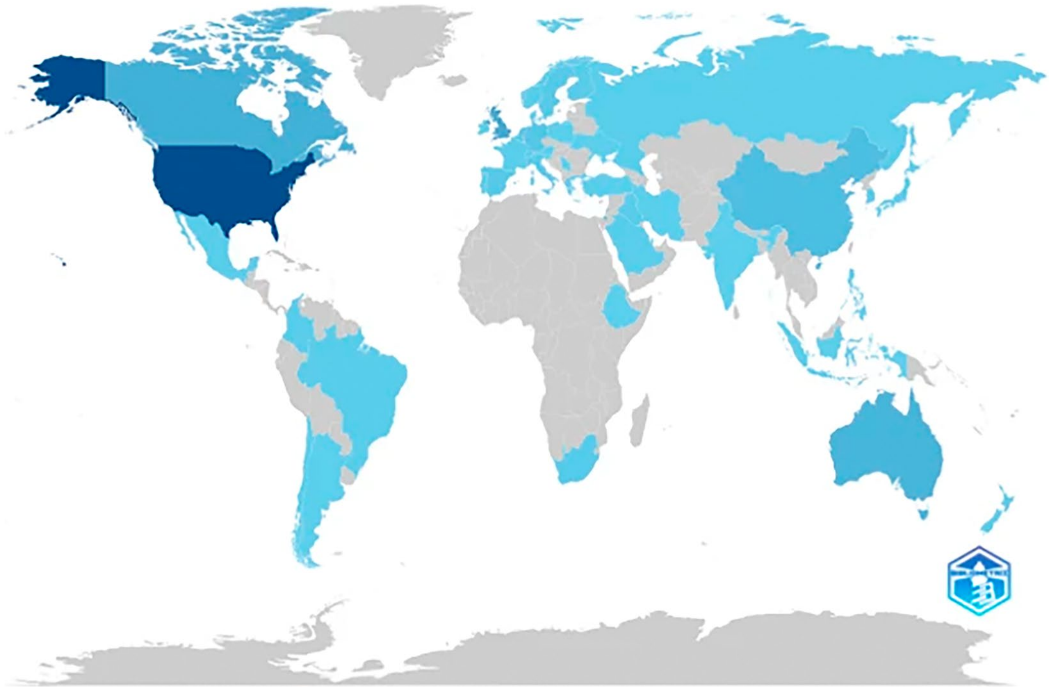

FIGURE 3 Scientific production by country network. (Different shades of blue indicate different productivity rates: Dark blue = high productivity, grey = no articles).

TABLE 6 Volumes and citations of research across countries.

Rank	Country	Frequency	Citation score
1st	USA	307	2183
2nd	UK	86	360
3rd	Canada	70	331
4th	Israel	60	276
5th	Australia	59	394

Co-citation network in BL and EDI research

To better understand the intellectual structure of the field, a co-citation network analysis was conducted to reveal how frequently cited authors are connected through shared references.

This analysis goes beyond citation frequency to uncover the underlying intellectual relationships among authors and institutions. It highlights how certain scholars—though not the most highly cited—act as conceptual bridges connecting theoretical and methodological communities. In this way, the co-citation map captures the structural dynamics of knowledge exchange within the field and illustrates how institutional collaborations contribute to shaping these intellectual linkages.

Figure 7 illustrates the co-citation network of key authors in the field. Two main clusters are visible:

- The green cluster centres on Hmelo-Silver, Jacobson, Wilensky, Yoon and Assaraf, linking to learning sciences and systems thinking.

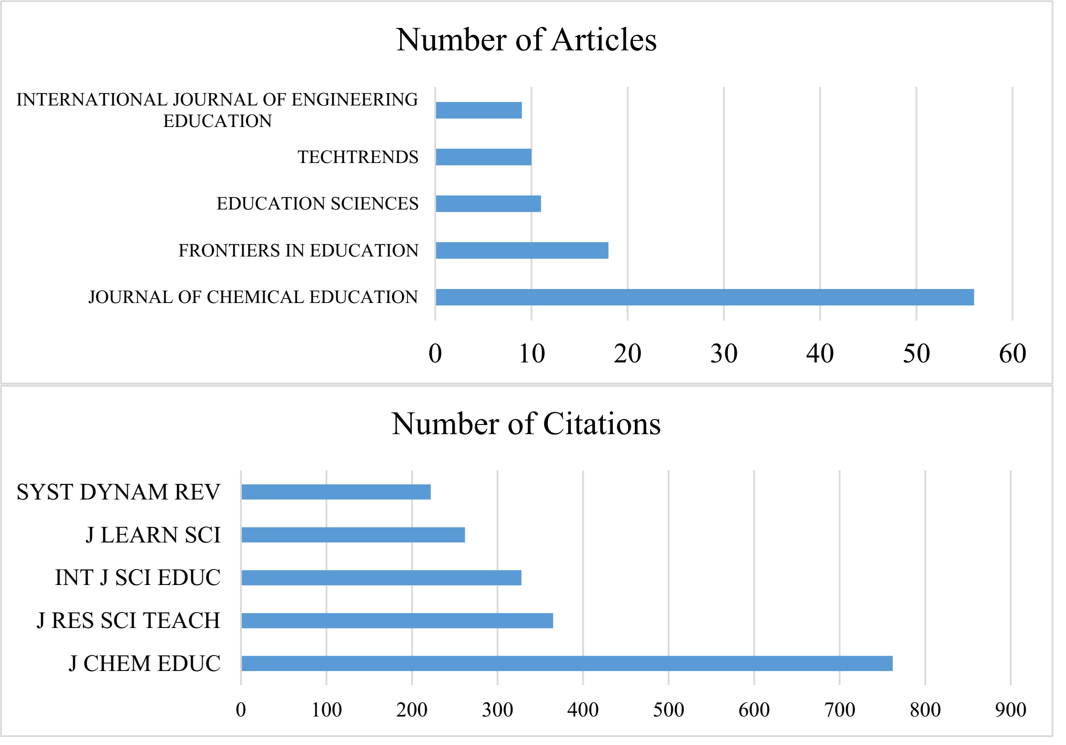

FIGURE 4 Leading journals and their citations.

- The red cluster includes Mahaffy, Senge, Arnold and York, reflecting themes in chemistry education and organizational learning.

This network reflects a maturing discourse with interdisciplinary convergence between pedagogical and domain-specific complexity frameworks.

Thematic mapping

Figure 8 presents a thematic map of the literature on complexity science in education, identifying clusters of research themes according to their centrality and development level.

In the thematic map (Figure 8), the four quadrants represent distinct categories of research themes. Motor themes are both highly developed and central to the field, reflecting mature and influential research areas that actively shape scholarly discourse. Basic themes are central but less developed, serving as the foundational core of the field while leaving room for further conceptual advancement. Niche themes are well-developed yet peripheral, representing specialized or context-bound topics with limited broader influence. Emerging or declining themes are underdeveloped or losing prominence, often indicating new directions or areas that have received limited recent attention.

Motor themes (Q1) such as 'instructional design', '"electronic adaptive training' and 'electronic courses' are located in the upper right quadrant, indicating their central and well-developed status. These themes are considered both highly central to the field and well-developed, indicating that they are not only conceptually mature but also actively shaping current research agendas. Their presence suggests a growing emphasis on technologically

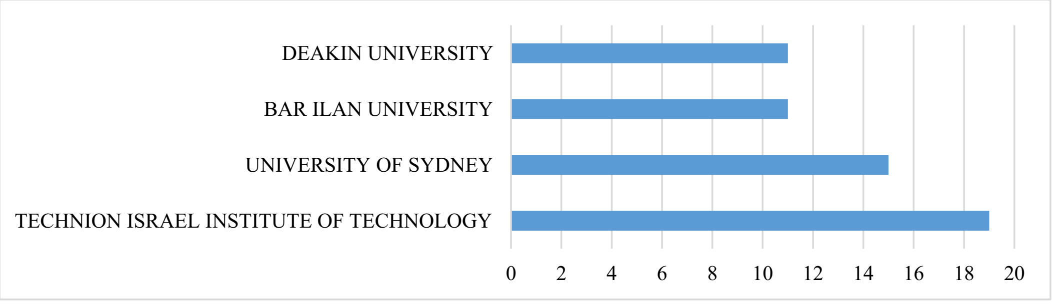

FIGURE 5 Leading institutions.

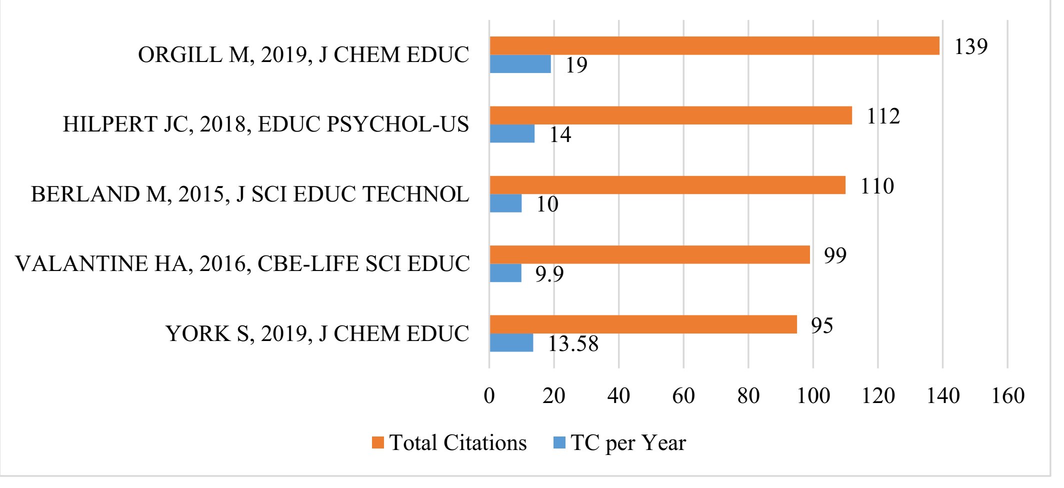

FIGURE 6 Most influential authors.

enriched learning environments where complexity principles are embedded within adaptive and personalized instructional frameworks.

The lower right quadrant (Q4) features basic and transversal themes like 'emergence', 'learning', 'systems thinking' and 'curriculum'. These are foundational to the field and serve as anchors for a wide range of studies. Their high centrality but lower development level implies that while these themes are essential, there remains room for deeper exploration and theoretical elaboration.

In the upper left quadrant (Q2), niche themes such as 'academic advising' and 'blended learning' are highly developed but less central. These topics may represent specialized domains with concentrated scholarly interest, potentially ripe for integration into broader conversations within the field. Their development suggests methodological rigour, but their limited connections to other themes may hinder their influence on mainstream complexity research in education.

The lower left quadrant (Q3) contains emerging or declining themes, including 'principals', 'design-based research' and 'complex adaptive systems'. These may reflect early-stage investigations or areas that have seen reduced scholarly attention. However, their placement also indicates opportunities for innovation, particularly if these themes can be linked to more central concerns in future research efforts.

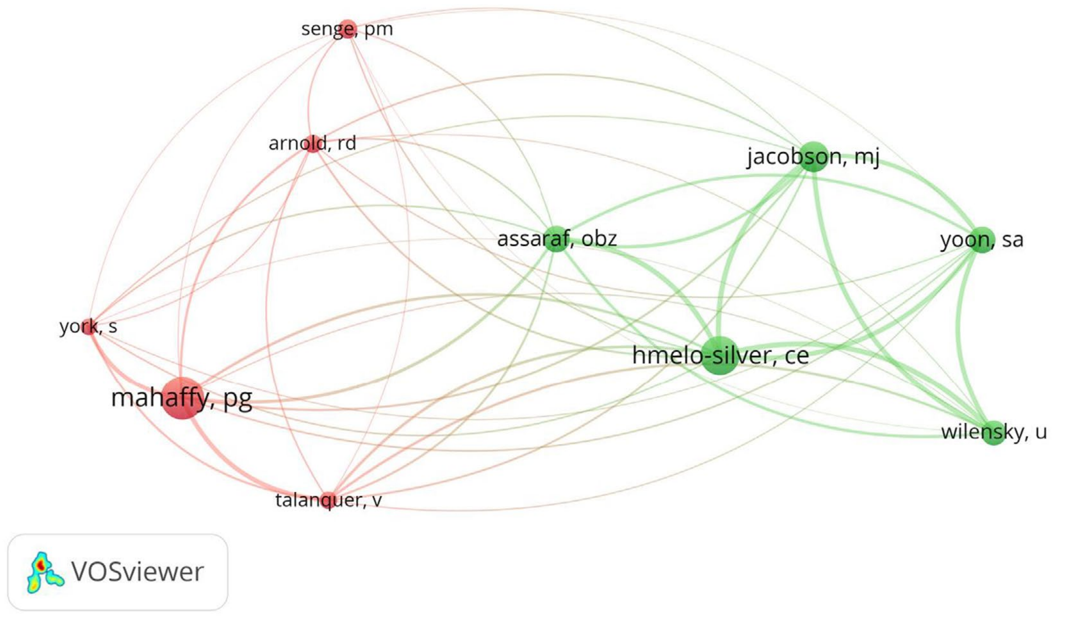

FIGURE 7 Co-citation network of authors.

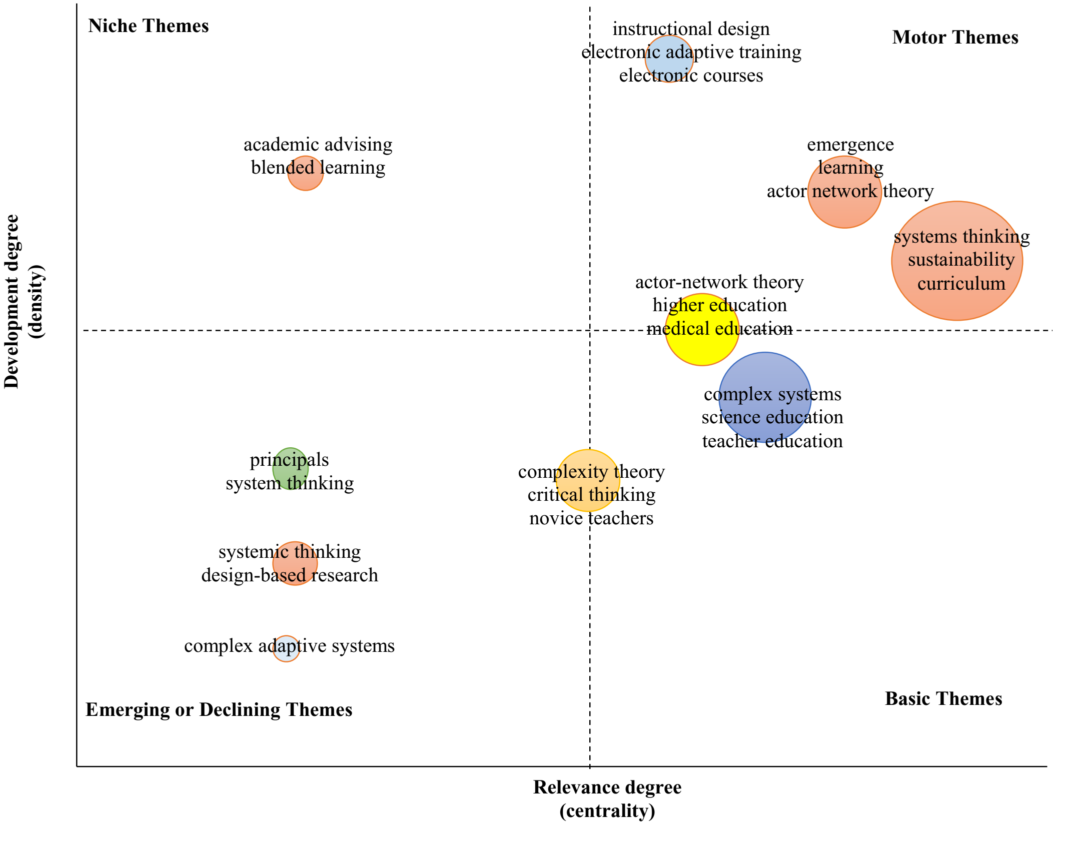

FIGURE 8 Thematic mapping of complexity science in education research.

Overall, the thematic map reveals a dynamic ecosystem of research topics—some firmly established, others on the rise or at risk of marginalization. It highlights the field's evolution and offers a roadmap for scholars aiming to expand or reorient their work within complexity science in education.

Analysis of keywords

Figure 9 below presents a keyword co-occurrence analysis of research on complexity science in education. This visualization maps the most frequently used terms and their co-usage, revealing the thematic structure and conceptual clusters within the literature.

Figure 9 presents a keyword co-occurrence analysis of the literature, mapping the most frequently used terms and their interrelations across studies. This network visualizes how core concepts in complexity science are connected within educational research and reveals the field's thematic architecture.

At the centre of the network lies ‘systems thinking’, the most dominant and frequently co-occurring keyword. Its centrality indicates its function as a conceptual and methodological hub, linking various subfields and applications. Terms closely associated with it—such as ‘curriculum’, ‘learning’, ‘sustainability’ and ‘self-organization’—highlight the diverse ways systems thinking informs both pedagogical theory and practice.

Surrounding this core, distinct clusters emerge. One prominent cluster includes terms like ‘green chemistry’, ‘environmental education’ and ‘decision-making’, which point to the application of complexity principles in sustainability and science education. Another cluster includes ‘teacher education’ ‘professional development’ and ‘instructional design’, reflecting research on educator competencies and the systemic transformation of teaching practices.

Keywords such as ‘actor-network theory’, ‘emergent learning’ and ‘adaptivity’ suggest a growing theoretical sophistication in the field. Their connections to central terms demonstrate efforts to integrate complexity theories into instructional and institutional

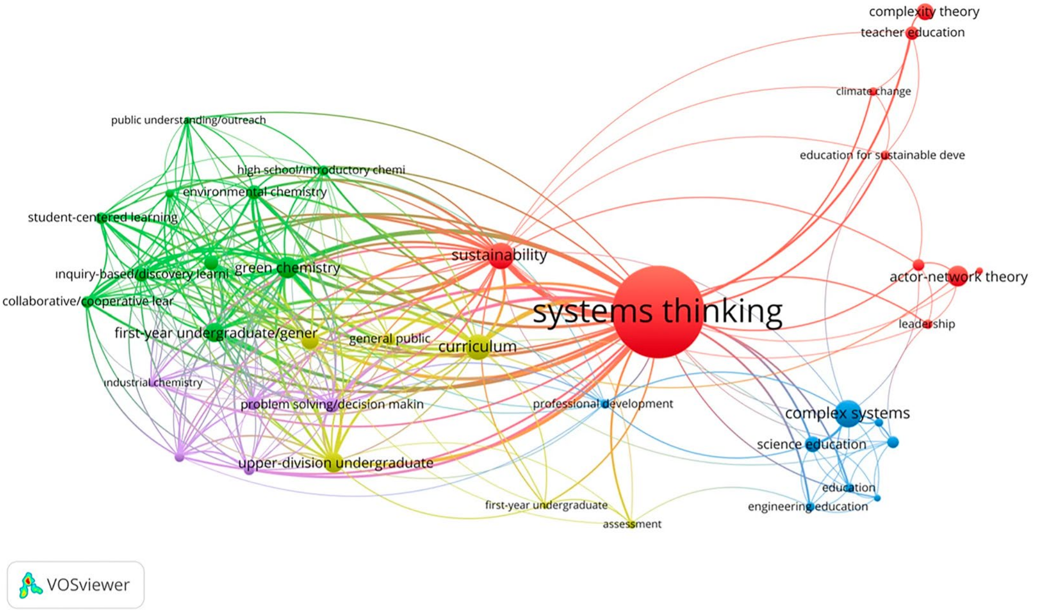

FIGURE 9 Keyword co-occurrence network in complexity science and education.

design. Moreover, practical concerns such as 'problem-solving', 'collaborative learning' and 'digital tools' reveal a strong emphasis on active learning and technology-enhanced environments.

The dense interlinking among keywords suggests a high degree of interdisciplinarity, with concepts crossing boundaries between cognitive science, environmental studies, instructional technology and educational leadership. This network structure indicates that complexity science in education is not a fragmented field but a highly integrated one, where theoretical insights, pedagogical models and applied innovations intersect.

CONCLUSION AND DISCUSSION

Although the intersection between complexity science and education has gained growing attention in recent years, there has been limited systematic effort to examine this domain in an integrated way. Complexity science provides a valuable theoretical framework for broadening perspectives on systems thinking, dynamic interactions and learning processes in education. Yet, in-depth analysis of how these principles are applied in educational contexts remains underexplored, with most studies focusing on narrow or fragmented aspects. This study responds to this need by integrating bibliometric mapping, content analysis and thematic synthesis to explore both conceptual and methodological patterns. Our bibliometric analysis covered 357 articles published between 2015 and 2024, retrieved from the Web of Science database. In addition, the 50 most influential articles from 2020 to 2024 were selected for content and thematic analysis, representing the most-cited studies from each year and offering key insights into the current literature. This combined approach, while based on a selective sample, enables an in-depth exploration of major trends and concepts and provides a structured basis for future research agendas. By combining multiple methodological layers, the study also offers a meta-analytical framework that can serve as a model for future reviews in related domains.

The content-based findings (RQ1) reveal key trends regarding how complexity science is interpreted in educational settings. In terms of participant profiles, undergraduate and K–12 students appear to be the most frequently selected groups. This may reflect both a growing interest in fostering systems thinking at multiple educational levels and the practical accessibility of these cohorts for researchers. Another possible explanation is that obtaining ethical approval and access to student groups is often easier compared to working with teachers or administrators. Similar results were also emphasized by Fisher and Systems Thinking Association (2023), who found that most studies primarily included students while empirical studies focusing on teachers or administrators were limited. This underrepresentation highlights a significant gap in understanding how systems thinking is interpreted and applied by educational practitioners (Jacobson & Wilensky, 2006).

Regarding data collection tools, the dominance of conventional methods—such as surveys and achievement tests—suggests that the field is still maturing and that researchers tend to rely on well-established techniques. This trend is supported by Nogueira (2023), which reports limited use of diverse methodologies. Nevertheless, the widespread use of qualitative instruments like interviews, observations and reflective notes suggests a growing recognition of contextual depth. Jacobson and Wilensky (2006) noted that systems-based studies often involve strong implementation contexts, encouraging the use of reflective and qualitative data. In some cases, the use of multiple data sources indicates that triangulation and multimodal approaches are valued in the field—an encouraging development for capturing the multifaceted nature of complex systems. It can be assumed that the reliance on traditional instruments reflects both the comfort zone of researchers and the need to establish methodological reliability in an emerging field.

In examining research variables, systems thinking skills emerged as the most frequently studied outcome, appropriately reflecting the field's core focus. Academic outcomes and literacy levels were also common variables, showing researchers' interest in both the development of systems thinking abilities and their relationship to traditional educational metrics. The presence of diverse 'other' variables suggests the field is still exploring which outcome measures are most relevant and meaningful.

Methodologically, qualitative designs—particularly case studies—are predominant, while a substantial number of conceptual papers suggest that the field is still in the process of refining its theoretical boundaries. This is in line with findings from Magrath et al. (2019), who reported that most studies related to systems research in education adopt qualitative approaches, whereas quantitative and mixed-method designs are still emerging. Similarly, Cao et al. (2025) note that studies in STEM contexts often lack methodological diversity and that practical, implementation-focused designs are limited. In contrast, Hebebci (2023) observed a growing use of experimental or quasi-experimental designs in STEM education. These findings indicate that while theoretically driven research continues to dominate, practical applications are gradually emerging, albeit with contextual variations. The limited methodological diversity may also be linked to the difficulty of operationalizing complex constructs in measurable terms, which calls for innovative designs that can balance rigour with ecological validity.

In terms of theoretical frameworks, systems thinking and complexity theory dominate, but ecological, sociocultural and interdisciplinary perspectives are also present. This diversity reflects a rich theoretical landscape, but it also reveals a lack of integration among conceptual traditions. As emphasized by Davis and Sumura (2006), there remains a need to develop holistic frameworks, particularly in domains like complex learning environments. One notable gap is the relative scarcity of applications in social sciences and education policy studies, which indicates that the uptake of complexity perspectives has been uneven across disciplines.

In terms of RQ2, the thematic analysis revealed five key dimensions of systems thinking in education: (1) diverse applications across educational settings, (2) measurable impacts on student development, (3) strong theoretical foundations, (4) practical implementation strategies and (5) emerging benefits and limitations. The widespread application of systems thinking—from K-12 sustainability projects to AI-enhanced higher education—suggests its versatility as both a pedagogical tool and a philosophical approach. This adaptability may stem from increasing recognition of complex, interconnected challenges in education and society. The consistent reports of improved higher-order thinking skills and social–emotional development across age groups imply that systems thinking inherently fosters 21st-century competencies, though this may depend on well-designed learning environments. These findings resonate with the broader literature on complexity-informed pedagogy, which emphasizes that systemic reasoning fosters resilience and adaptability in learners (Yoon et al., 2018).

The rich theoretical grounding in complexity, ecological systems and dynamic systems theories points to an interdisciplinary effort to understand education as a multilayered system. However, the dominance of theoretical papers in RQ1's findings contrasts with RQ2's emphasis on practical implementations (e.g. modelling tools, interdisciplinary scenarios). This tension may reflect an ongoing transition from conceptualization to classroom application, with practitioners adapting theories to local contexts. Notable limitations—teacher preparedness, curricular constraints and age-appropriate designs—hint at systemic barriers to implementation. These challenges likely arise from traditional education structures that prioritize linear over systemic approaches. Future directions emphasizing digital tools (AI, AR) and ethical frameworks suggest the field is evolving towards more immersive, justice-oriented applications, possibly in response to global crises requiring systemic solutions.

In terms of RQ3, the relatively small number of publications suggests complexity science in education is still emerging—likely due to the conceptual difficulty of applying systems frameworks in educational contexts. Despite this, steady publication rates and high citation averages signal growing scholarly interest. The field exhibits developmental traits, especially in collaboration: international co-authorship is modest, and most contributions come from Anglo-Saxon countries, particularly the US, UK and Australia. This concentration may not only be a result of stronger research infrastructures but also of the dominance of English as the global language of academic publishing (Durak et al., 2024). The field shows moderate interdisciplinarity, though a notable number of single-authored works indicate that it is still negotiating between individual theoretical development and collaborative synthesis across disciplines. The United States dominates the research landscape, a pattern aligned with substantial national investments in research ecosystems (Durak et al., 2024; Hebebci, 2023; Talan, 2021). The strong presence of the UK and Australia further reflects this tradition. However, the geographic concentration signals a need for more diverse international engagement to broaden perspectives.

Journal analysis shows the JCE as the most influential outlet, likely due to chemistry's natural alignment with systemic and emergent properties. Other active journals include Frontiers in Education and Education Sciences, indicating growing pedagogical interest in complexity perspectives. Co-citation analysis revealed two clusters: one grounded in learning sciences, the other in discipline-specific applications like chemistry and organizational learning. These clusters highlight promising theoretical convergence, though further cross-disciplinary integration is still needed. Keyword and thematic analyses emphasize central themes such as 'systems thinking', 'curriculum' and 'learning'. Well-developed motor themes include 'instructional design' and 'adaptive e-learning', while niche areas like 'academic advising' and 'blended learning' remain underexplored. In light of the rapid digitalization of education, future research may particularly benefit from integrating AI-driven analytics and adaptive systems within a complexity framework, which could enhance both theoretical modelling and practical applications.

Taken together, these findings demonstrate that the intersection of complexity science and education holds strong potential both theoretically and practically. Yet, to realize this potential fully, key gaps must be addressed: expanding research on teacher and administrator roles, promoting multimodal and digital data collection approaches, ensuring greater geographical diversity and strengthening theoretical integration. Increasing international collaboration, leveraging digital systems to support systemic learning, and developing justice-oriented frameworks will further enable complexity-informed perspectives to make meaningful contributions to education. Beyond these substantive insights, the present study also contributes methodologically by illustrating the value of combining bibliometric, content and thematic analyses in a single framework, offering a pathway for more comprehensive future reviews.

LIMITATIONS AND SUGGESTIONS

This study offers valuable insights into the use of complexity sciences in education but is not without limitations. First, the bibliometric analysis relied solely on the Web of Science database, possibly excluding relevant studies from other sources. Second, restricting the review to English-language publications may have overlooked significant work in other languages. Third, the focus on peer-reviewed journal articles meant that influential contributions in books, book chapters, dissertations and conference proceedings were not included, which may have limited the comprehensiveness of the review. Fourth, the limited sample size (357 publications) reflects the field's emerging status and affects the generalizability of results. Future studies should include multiple databases (e.g. Scopus) for broader coverage and engage international teams to support cross-cultural comparisons. From a methodological standpoint, the frequent use of self-report and survey methods points to the need for more objective and diverse data collection strategies, including digital and real-time tools. The limited focus on educators and administrators highlights a practical gap. Expanding teacher education programs to include complexity-based approaches and supporting professional development could improve classroom integration. To achieve broader educational transformation, complexity science must also inform policy. Collaborative studies involving policymakers, researchers and practitioners are essential. Lastly, integrating technologies such as AI and learning analytics with complexity-based models offers significant promise but requires stronger technical and pedagogical infrastructure.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

Ethical approval was not required for this study because it is a scoping review and did not involve human participants, identifiable personal data, or experimental interventions.

REFERENCES

Aria, M., & Cuccurullo, C. (2017). *bibliometrix*: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, *11*(4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007

Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology*, *8*(1), 19–32. https://doi.org/10.1080/1364557032000119616

Arnold, R. D., & Wade, J. P. (2015). A definition of systems thinking: A systems approach. *Procedia Computer Science*, *44*, 669–678. https://doi.org/10.1016/j.procs.2015.03.050

Batt, A. M., Williams, B., Brydges, M., Leyenaar, M., & Tavares, W. (2021). New ways of seeing: Supplementing existing competency framework development guidelines with systems thinking. *Advances in Health Sciences Education*, *26*(4), 1355–1371. https://doi.org/10.1007/s10459-021-10054-x

Berland, M., & Wilensky, U. (2015). Comparing virtual and physical robotics environments for supporting complex systems and computational thinking. *Journal of Science Education and Technology*, *24*(5), 628–647. https://doi.org/10.1007/s10956-015-9552-x

Boersma, K., Waarlo, A. J., & Klaassen, K. (2011). The feasibility of systems thinking in biology education. *Journal of Biological Education*, *45*(4), 190–197. https://doi.org/10.1080/00219266.2011.627139

Brychkov, D., McKeown, P. C., Domegan, C., Spillane, C., & Brychkova, G. (2024). "Connect the circle" systems thinking tool for postgraduate sustainability education: Case study. *International Journal of Sustainability in Higher Education*, *25*(9), 437–454. https://doi.org/10.1108/IJSHE-10-2023-0507

Byrne, D., & Callaghan, G. (2013). *Complexity theory and the social sciences*. Routledge. https://doi.org/10.4324/9780203519585

Cao, X., Lu, H., Wu, Q., & Hsu, Y. (2025). Systematic review and meta-analysis of the impact of STEM education on students learning outcomes. *Frontiers in Psychology*, *16*, 1579474. https://doi.org/10.3389/fpsyg.2025.1579474

Chaaban, Y., Al-Thani, H., & Du, X. (2024). A systems-thinking approach to evaluating a university professional development programme. *Professional Development in Education*, *50*(2), 296–314. https://doi.org/10.1080/19415257.2023.2193199

Costa, A. P., Moresi, E. D., Pinho, I., & Halaweh, M. (2023). Integrating bibliometrics and qualitative content analysis for conducting a literature review. In *2023 24th International Arab Conference on Information Technology (ACIT)* (pp. 1–8). IEEE. https://doi.org/10.1109/ACIT58888.2023.10453680

Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed.). Sage.

Davis, B., & Sumura, D. (2006). *Complexity and education: Inquiries into learning, teaching, and research*. Routledge. https://www.routledge.com/Complexity-and-Education-Inquiries-Into-Learning-Teaching-and-Research/Davis-Sumara/p/book/9780805859355

Demssie, Y. N., Biemans, H. J. A., Wesselink, R., & Mulder, M. (2023). Fostering students' systems thinking competence for sustainability by using multiple real-world learning approaches. *Environmental Education Research*, *29*(2), 261–286. https://doi.org/10.1080/13504622.2022.2141692

Dever, D. A., Sonnenfeld, N. A., Wiedbusch, M. D., Schmorrow, S. G., Amon, M. J., & Azevedo, R. (2023). A complex systems approach to analyzing pedagogical agents' scaffolding of self-regulated learning within an intelligent tutoring system. *Metacognition and Learning*, *18*(3), 659–691. https://doi.org/10.1007/s11409-023-09346-x

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, *133*, 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070

Durak, G., Cankaya, S., Yunkul, E., & Misirli, Z. A. (2018). A content analysis of dissertations in the field of educational technology: The case of Turkey. *Turkish Online Journal of Distance Education*, *19*(2), 128–148. https://doi.org/10.17718/tojde.415827

Durak, G., Çankaya, S., Özdemir, D., & Can, S. (2024). Artificial intelligence in education: A bibliometric study on its role in transforming teaching and learning. *The International Review of Research in Open and Distributed Learning*, *25*(3), 219–244. https://doi.org/10.19173/irrodl.v25i3.7757

Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of Advanced Nursing*, *62*(1), 107–115. https://doi.org/10.1111/j.1365-2648.2007.04569.x

Erlingsson, C., & Brysiewicz, P. (2017). A hands-on guide to doing content analysis. *African Journal of Emergency Medicine*, *7*(3), 93–99. https://doi.org/10.1016/j.afjem.2017.08.001

Fisher, D. M., & Systems Thinking Association. (2023). Systems thinking activities used in K-12 for up to two decades. *Frontiers in Education*, *8*, 1059733. https://doi.org/10.3389/feduc.2023.1059733

Ford, D. N. (2019). A system dynamics glossary. *System Dynamics Review*, *35*(4), 369–379. https://doi.org/10.1002/sdr.1641

Gilissen, M. G. R., Knippels, M.-C. P. J., & Van Joolingen, W. R. (2020). Bringing systems thinking into the classroom. *International Journal of Science Education*, *42*(8), 1253–1280. https://doi.org/10.1080/09500693.2020.1755741

Hebebci, M. T. (2023). A systematic review of experimental studies on STEM education. *Journal of Education in Science, Environment and Health*, *9*(1), 56–73. https://doi.org/10.55549/jeseh.1239074

Hilpert, J. C., & Marchand, G. C. (2018). Complex systems research in educational psychology: Aligning theory and method. *Educational Psychologist*, *53*(3), 185–202. https://doi.org/10.1080/00461520.2018.1469411

Jackson, M. C. (2019). *Critical systems thinking and the management of complexity: Responsible leadership for a complex world*. Wiley.

Jacobson, M. J., Levin, J. A., & Kapur, M. (2019). Education as a complex system: Conceptual and methodological implications. *Educational Researcher*, *48*(2), 112–119. https://doi.org/10.3102/0013189X19826958

Jacobson, M. J., & Wilensky, U. (2006). Complex systems in education: Scientific and educational importance and implications for the learning sciences. *Journal of the Learning Sciences*, *15*(1), 11–34. https://doi.org/10.1207/s15327809jls1501_4

Kaplan, A., & Garner, J. K. (2020). Steps for applying the complex dynamical systems approach in educational research: A guide for the perplexed scholar. *The Journal of Experimental Education*, *88*(3), 486–502. https://doi.org/10.1080/00220973.2020.1745738

Kopnina, H., & Meijers, F. (2014). Education for sustainable development (ESD): Exploring theoretical and practical challenges. *International Journal of Sustainability in Higher Education*, *15*(2), 188–207. https://doi.org/10.1108/IJSHE-07-2012-0059

Leisner, C. P., Potnis, N., & Sanz-Saez, A. (2023). Crosstalk and trade-offs: Plant responses to climate change-associated abiotic and biotic stresses. *Plant, Cell & Environment*, *46*(10), 2946–2963. https://doi.org/10.1111/pce.14532

Liang, Y., Xiao, Z., Wang, S., Li, Y., & Li, H. (2024). An interdisciplinary practical project for preservice science teachers: Visualizing climate change based on systems thinking. *Journal of Chemical Education*, *101*(7), 2682–2692. https://doi.org/10.1021/acs.jchemed.3c01271

Liu, S.-C. (2023). Examining undergraduate students' systems thinking competency through a problem scenario in the context of climate change education. *Environmental Education Research*, *29*(12), 1780–1795. https://doi.org/10.1080/13504622.2022.2120187
Magrath, B., Aslam, M., & Johnson, D. (2019). Systems research in education: Designs and methods. *Research in Comparative and International Education*, *14*(1), 7–29. https://doi.org/10.1177/1745499919828927
Mambrey, S., Timm, J., Landskron, J. J., & Schmiemann, P. (2020). The impact of system specifics on systems thinking. *Journal of Research in Science Teaching*, *57*(10), 1632–1651. https://doi.org/10.1002/tea.21649
Mitchell, M. (2011). *Complexity: A guided tour*. Oxford University Press.
Momsen, J., Speth, E. B., Wyse, S., & Long, T. (2022). Using systems and systems thinking to unify biology education. *CBE Life Sciences Education*, *21*(2), es3. https://doi.org/10.1187/cbe.21-05-0118
Nieminen, J., & Pesonen, H. (2022). Anti-ableist pedagogies in higher education: A systems approach. *Journal of University Teaching and Learning Practice*, *19*(4), 1–15. https://doi.org/10.53761/1.19.4.8
Nogueira, B. (2023). The emergence of complexity thinking and its influence on educational research. *Canadian Journal for New Scholars in Education*, *14*(1), 98–105.
Orgill, M., York, S., & MacKellar, J. (2019). Introduction to systems thinking for the chemistry education community. *Journal of Chemical Education*, *96*(12), 2720–2729. https://doi.org/10.1021/acs.jchemed.9b00169
Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, *372*. https://doi.org/10.1136/bmj.n71
Parry, S., & Metzger, E. (2023). Barriers to learning for sustainability: A teacher perspective. *Sustainable Earth Reviews*, *6*(1), 2. https://doi.org/10.1186/s42055-022-00050-3
Pekrun, R. (2024). Overcoming rragmentation in motivation science: Why, when, and how should we integrate theories? *Educational Psychology Review*, *36*(1), 27. https://doi.org/10.1007/s10648-024-09846-5
Plano Clark, V. L., & Ivankova, N. V. (2016). *Mixed methods research: A guide to the field*. SAGE.
Reynders, M., Pilcher, L. A., & Potgieter, M. (2023). Teaching and assessing systems thinking in first-year chemistry. *Journal of Chemical Education*, *100*(3), 1357–1365. https://doi.org/10.1021/acs.jchemed.2c00891
Rojas, M. P., & Chiappe, A. (2024). Artificial intelligence and digital ecosystems in education: A review. *Technology, Knowledge and Learning*, *29*(4), 2153–2170. https://doi.org/10.1007/s10758-024-09732-7
Sajja, R., Sermet, Y., Cwiertny, D., & Demir, I. (2025). Integrating AI and learning analytics for data-driven pedagogical decisions and personalized interventions in education. *Technology, Knowledge and Learning*, 1–13. https://doi.org/10.1007/s10758-025-09897-9
Santos, C. M., Franco, R. A., Leon, D., Ovigli, D. B., & Colombo Junior, P. D. (2017). Interdisciplinarity in education: Overcoming fragmentation in the teaching-learning process. *International Education Studies*, *10*(10), 71–77. https://doi.org/10.5539/ies.v10n10p71
Saqr, M., & López-Pernas, S. (2024). Mapping the self in self-regulation using complex dynamic systems approach. *British Journal of Educational Technology*, *55*(4), 1376–1397. https://doi.org/10.1111/bjet.13452
Shephard, K. (2023). Academic identity and "education for sustainable development": A grounded theory. *Frontiers in Education*, *8*, 1257119. https://doi.org/10.3389/feduc.2023.1257119
Shin, N., Bowers, J., Roderick, S., McIntyre, C., Stephens, A. L., Eidin, E., Krajcik, J., & Damelin, D. (2022). A framework for supporting systems thinking and computational thinking through constructing models. *Instructional Science*, *50*(6), 933–960. https://doi.org/10.1007/s11251-022-09590-9
Strijbos, J.-W., Martens, R. L., Prins, F. J., & Jochems, W. M. G. (2006). Content analysis: What are they talking about? *Computers & Education*, *46*(1), 29–48. https://doi.org/10.1016/j.compedu.2005.04.002
Sweeney, L. B., & Sterman, J. D. (2007). Thinking about systems: Student and teacher conceptions of natural and social systems. *System Dynamics Review*, *23*(2–3), 285–311. https://doi.org/10.1002/sdr.366
Tahamtan, I., Safipour Afshar, A., & Ahamdzadeh, K. (2016). Factors affecting number of citations: A comprehensive review of the literature. *Scientometrics*, *107*(3), 1195–1225. https://doi.org/10.1007/s11192-016-1889-2
Talan, T. (2021). Artificial intelligence in education: A bibliometric study. *International Journal of Research in Education and Science*, *7*(3), 822–837. https://doi.org/10.46328/ijres.2409
Thelen, E., & Smith, L. B. (1994). *A dynamic systems approach to the development of cognition and action*. MIT Press.
Valantine, H. A., Lund, P. K., & Gammie, A. E. (2016). From the NIH: A systems approach to increasing the diversity of the biomedical research workforce. *CBE Life Sciences Education*, *15*(3), fe4. https://doi.org/10.1187/cbe.16-03-0138
White, M. D., & Marsh, E. E. (2006). Content analysis: A flexible methodology. *Library Trends*, *55*(1), 22–45. https://doi.org/10.1353/lib.2006.0053
Yoon, S. A., Goh, S.-E., & Park, M. (2018). Teaching and learning about complex systems in K–12 science education: A review of empirical studies 1995–2015. *Review of Educational Research*, *88*(2), 285–325. https://doi.org/10.3102/0034654317746090
York, S., Lavi, R., Dori, Y. J., & Orgill, M. (2019). Applications of systems thinking in STEM education. *Journal of Chemical Education*, *96*(12), 2742–2751. https://doi.org/10.1021/acs.jchemed.9b00261

Zhong, Y., Guo, K., & Chu, S. K. W. (2024). Affordances and constraints of integrating esports into higher education from the perspectives of students and teachers: An ecological systems approach. *Education and Information Technologies*, *29*(13), 16777–16811. https://doi.org/10.1007/s10639-024-12482-9

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