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HOW HAS SYSTEMS THINKING EVOLVED IN TURKISH SCIENCE EDUCATION? A SYSTEMATIC REVIEW (2015–2025)

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ABSTRACT

This systematic review aims to examine the evolution and current landscape of systems thinking research within the field of science education in Türkiye over the past decade (2015–2025). Guided by the PRISMA 2020 framework, 22 empirical studies—including peer-reviewed journal articles and graduate theses—were analyzed through descriptive content analysis. Data were drawn from national and international databases such as the Council of Higher Education Thesis Center (CHE), ERIC, EBSCOhost, Web of Science, and Google Scholar. Findings indicate that the majority of studies employed qualitative research designs, focusing predominantly on preservice science teachers and middle school students. Thematically, systems thinking has been most commonly addressed in the contexts of sustainability, environmental education, and life cycles. However, limited attention has been paid to interdisciplinary domains such as social systems, ethical reasoning, or curriculum literacy. Additionally, the use of validated instruments remains scarce, and regional representation is largely confined to a few metropolitan areas, with notable gaps in studies conducted in rural and underrepresented regions. While interest in systems thinking in Turkish science education has grown significantly since 2019, particularly in response to national curriculum revisions, methodological diversity and depth remain limited.

Keywords: Systems thinking, science education, Türkiye, systematic review, sustainability education.

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INTRODUCTION

In today's rapidly changing world, traditional linear thinking approaches are often insufficient to address the complexity and interconnectedness of real-world problems. As global challenges increasingly demand integrative and multidimensional solutions, systems thinking has emerged as a powerful paradigm for understanding dynamic structures, causal relationships, and feedback loops across disciplines (Sterman, 2000). At its core, systems thinking emphasizes the ability to analyze wholes rather than isolated parts, and it promotes the capacity to make sense of complex phenomena by identifying interdependencies, modeling structures, and predicting long-term consequences (Meadows, 2008). These skills are particularly critical in fostering informed decision-making and sustainable living in an era characterized by environmental uncertainty and socio-technical complexity.

Given its emphasis on holistic reasoning and the interpretation of dynamic systems, systems thinking has strong pedagogical relevance in science education. While science education aims to cultivate scientific literacy, analytical reasoning, and problem-solving skills, systems thinking deepens these competencies by encouraging students to explore conceptual linkages between scientific topics and their societal, environmental, and economic contexts (Assaraf & Orion, 2005). International literature has increasingly emphasized the integration of systems thinking in science curricula. Empirical studies from countries such as the United States, Germany, Finland, Singapore, and Australia have shown that systems-based instruction enhances students' process-oriented and conceptual understanding (Booth Sweeney & Sterman, 2007; Yoon et al., 2018). These studies commonly assess students' modeling abilities, diagrammatic thinking, causal reasoning, and problem-solving performance, reporting positive impacts on academic achievement and cognitive development.

In Türkiye, systems thinking has recently begun to attract growing academic interest, especially in educational research. However, compared to the international literature, the number of empirical studies in this area remains limited, and much of the existing work is predominantly descriptive or theoretical in nature. Only a small portion of the literature is composed of intervention-based or design-based research. A few graduate theses and peer-reviewed articles have employed visual tools, concept mapping, and systems diagrams to assess systems thinking skills (Turan, 2019; Tezcan, 2024; Güven, 2025).

With the 2024 revision of the Turkish Ministry of National Education's Science Curriculum (Ministry of National Education [MoNE], 2024), systems thinking has started to gain greater prominence at the policy level. Under the unit titled "Sustainable Living," students are encouraged to engage in activities such as analyzing ecological systems, questioning human impacts on nature, and developing systems-based solution maps. However, as this curriculum is newly implemented, the pedagogical implications and practical outcomes of these changes remain to be systematically evaluated.

Although the theoretical foundations and international applications of systems thinking are well established, its integration into Türkiye's educational system is still in a developmental stage. There is a clear need for an increase in high-quality, practice-oriented research, as well as more effective embedding of systems thinking into science curricula and teacher education programs. This systematic review seeks to address this gap by mapping the current landscape of systems thinking research in the context of science education in Türkiye. Specifically, the aim of the study is to examine academic research conducted between 2015 and 2025 to identify key trends, methodological orientations, and thematic priorities in the field.

The purpose and significance of this study lie in its systematic synthesis of systems thinking research within the domain of science education in Türkiye over the past decade (2015–2025). While global literature on systems thinking in science education has matured through numerous empirical investigations, Türkiye's contributions remain relatively sparse, fragmented, and often limited to theoretical or descriptive analyses. This study not only addresses this gap by offering a comprehensive overview of national research trends but also critically evaluates methodological orientations and thematic patterns within the existing body of work.

By identifying underexplored areas—such as quantitative assessment, intervention-based designs, and regional diversity in sampling—this review contributes to the development of a more robust research agenda in Turkish science education. Moreover, it provides actionable insights for curriculum developers, teacher educators, and policymakers seeking to embed systems thinking more effectively in formal science instruction. Ultimately, this review enhances the global discourse by bringing a contextualized understanding of how systems thinking is conceptualized and operationalized in a non-Western educational setting, thus offering comparative value to international literature.

METHOD

Research Design

This study adopted a systematic review design to explore how systems thinking has been addressed in the field of science education in Türkiye between 2015 and 2025. Systematic reviews are recognized as rigorous and evidence-based methodologies that utilize clearly defined procedures to locate, appraise, and synthesize findings from existing literature (Tutar & Erdem, 2020). Rather than generating new empirical data, this design focuses on aggregating previously published studies to identify methodological trends, thematic concentrations, and conceptual framings.

The review process followed the guidelines set forth in the PRISMA 2020 statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), which ensures that literature syntheses are conducted with transparency and reproducibility (Page et al., 2021). The PRISMA framework was used to guide all stages of the review, including the formulation of search queries, the screening and selection of eligible studies, and the visual presentation of the process (Figure 1).

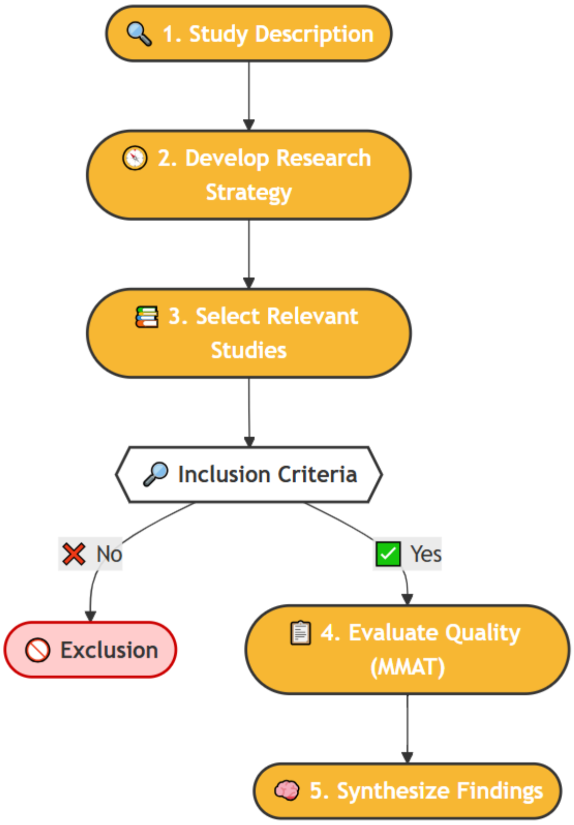

Figure 1. Systematic Review Workflow Based on PRISMA and MMAT Guidelines

Figure 1 illustrates the structured workflow adopted in this systematic review, designed in alignment with the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) and MMAT 2018 (Mixed Methods Appraisal Tool) frameworks. The process comprises five sequential stages: (1) Study Identification, (2) Search Strategy Development, (3) Screening and Selection of Relevant Studies, (4) Quality Appraisal using MMAT, and (5) Data Synthesis and Reporting of findings. Each stage ensures methodological transparency and replicability, thereby enhancing the scientific rigor of the review. At the critical decision point labeled "Inclusion Criteria Met?", studies are assessed based on predefined eligibility conditions. Those that meet the inclusion criteria proceed to quality appraisal and synthesis, while studies that do not meet the criteria are excluded from the analysis. This flow ensures that only methodologically sound and thematically relevant studies are incorporated into the final review, supporting the reliability and validity of the conclusions drawn.

Data Sources and Search Strategy

To ensure the comprehensiveness of this systematic review, an extensive search strategy was developed based on a preliminary examination of the relevant literature on systems thinking within science education. This initial exploration enabled the identification of commonly used terms in both Turkish and English academic publications. The final list of search terms included combinations of phrases such as *"systems thinking," "system thinking approach," "systems thinking model," "sistem düşüncesi," "sistemsel düşünme," "sistem düşünme* *yaklaşımı,"* as well as *"science education"* and *"fen eğitimi."* Boolean operators, specifically AND and OR, were applied in various combinations to optimize the search across different databases. Figure 2 provides an illustration of the search logic and term structure employed in the study.

The search was conducted across five major academic databases that are widely recognized for their relevance to educational research. These databases were the Council of Higher Education Thesis Center in Türkiye, the Education Resources Information Center, EBSCOhost, Web of Science, and Google Scholar. The inclusion of both national and international databases ensured that the review covered peer-reviewed journal articles, graduate theses, and grey literature, thereby offering a comprehensive view of academic work produced in Türkiye. The search was limited to studies published between January 2015 and March 2025 to reflect contemporary trends, including the influence of recent curriculum reforms in Türkiye.

Eligibility Criteria

Clear inclusion and exclusion criteria were defined prior to the screening of studies to ensure consistency and transparency. Studies were eligible for inclusion if they:

- Were published between 2015 and 2025,
- Focused on the domain of science education,
- Addressed systems thinking as either a central theme or an integrated educational approach,
- Targeted populations such as secondary school students, high school students, pre-service science teachers, or in-service educators,
- Were conducted in Türkiye.

Studies were excluded if they:

- Belonged to disciplines outside of science education, such as engineering or economics,
- Lacked an empirical research framework, including essays or purely theoretical discussions,
- Were unavailable in full-text form despite efforts to retrieve them.

The flow of study selection, including identification, screening, eligibility assessment, and final inclusion, is summarized in Figure 2. This diagram provides a clear and transparent overview of how studies were filtered and selected for synthesis in accordance with the review protocol.

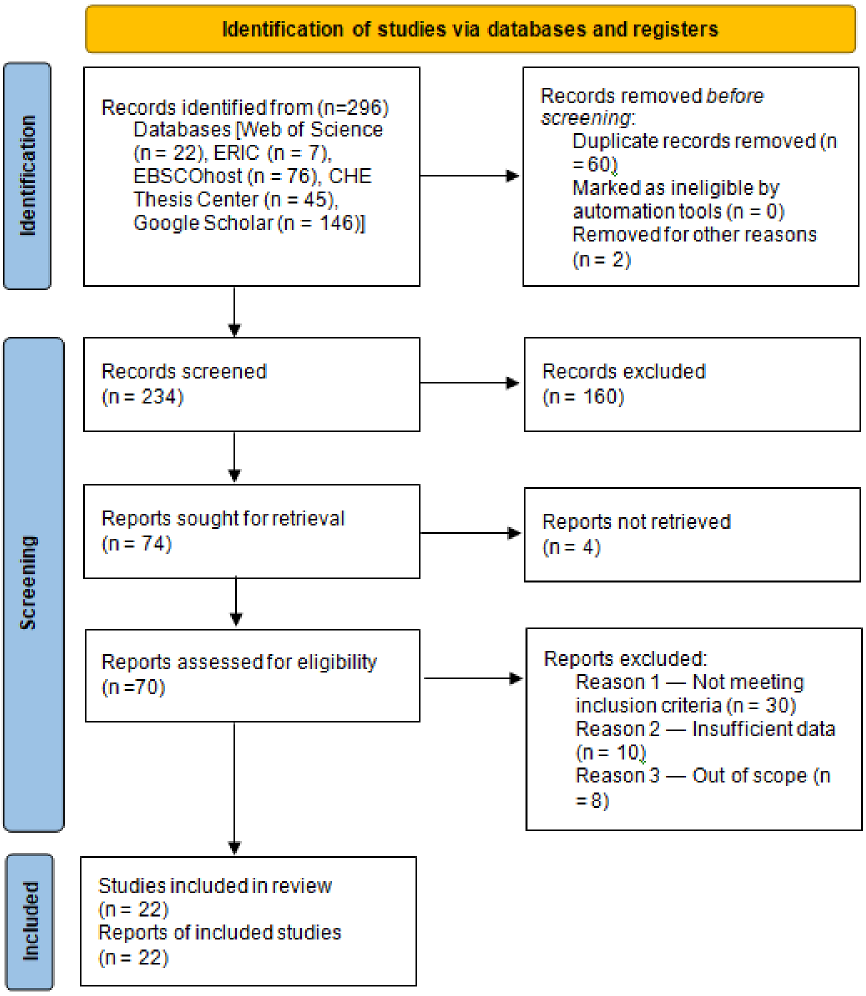

Figure 2. PRISMA 2020 Flow Diagram İllustrating The Study Selection Process

Figure 2 summarizes the flow of records through the phases of identification, screening, eligibility, and inclusion in the systematic review. Records were identified through database searches, duplicates and ineligible records were removed, and studies were assessed for eligibility. A total of 22 studies were included in the final synthesis.

Quality Assessment

The methodological rigor of the included studies was assessed using the Mixed Methods Appraisal Tool, 2018 edition. This instrument is designed to evaluate the quality of qualitative, quantitative, and mixed-methods research through criteria tailored to each study type. Each publication was independently evaluated by two reviewers to enhance objectivity. When discrepancies occurred in scoring, they were resolved through discussion. Studies that failed to meet the minimum quality standards, defined as fulfilling at least three of the five applicable criteria, were excluded from the final synthesis to ensure the reliability of the review findings.

Data Analysis

All included studies were analyzed using descriptive content analysis. A structured coding framework was employed to categorize studies according to publication year, type of publication (for example, journal article, master's thesis, or doctoral dissertation), research design (qualitative, quantitative, or mixed-methods), participant characteristics, data collection tools, thematic focus, and geographical distribution within Türkiye. The results of the analysis were presented using tables and figures to clearly convey patterns, trends, and gaps identified in the national research landscape. In addition, the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram was used to visually represent the study selection process and enhance the transparency of the review.

FINDINGS

This section presents the findings of the systematic review, which synthesized 22 empirical studies conducted in Türkiye between 2015 and 2025 on the integration of systems thinking into science education. The studies were analyzed across eight dimensions: year of publication, type of publication, participant groups, methodological orientation, data collection tools, thematic focus, geographical representation, and conceptual emphasis. The results are supported by a series of visual figures to provide a comprehensive and structured account of national research trends in this domain.

Annual Trends in Publication Output

The yearly distribution of publications reveals a clear upward trajectory in academic attention to systems thinking over the last decade. Between 2015 and 2018, the number of studies was minimal and sporadic. However, beginning in 2019, a sustained increase is evident, culminating in a peak in 2023. This rise coincides with increased global focus on sustainability, the proliferation of interdisciplinary STEM initiatives, and national curriculum revisions introduced by the Turkish Ministry of National Education in 2024. While the number of studies slightly declined in 2025, this is likely due to the May 2025 data cut-off (Figure 3).

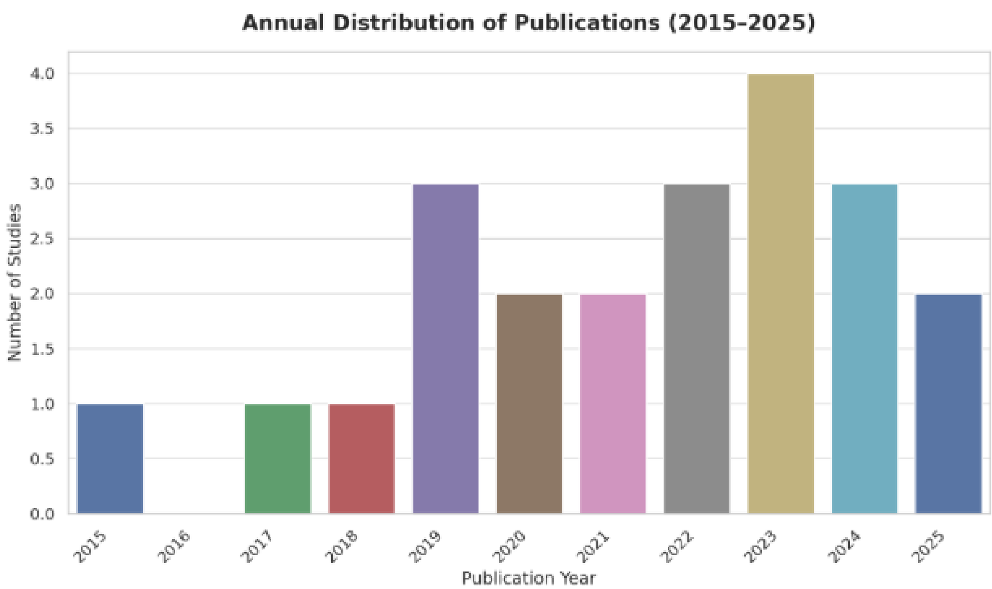

Figure 3. Annual Distribution of Systems Thinking Research in Turkish Science Education (2015–2025)

As shown in Figure 3, scholarly interest in systems thinking within the context of Turkish science education has demonstrated a growing trajectory over the past decade. From 2015 to 2018, research output remained sparse and exploratory in nature. However, beginning in 2019, a significant increase in publication volume is observed, likely reflecting global educational trends related to sustainability and complexity, as well as national curricular shifts emphasizing systems-based competencies.

The publication peak in 2023 may be attributed to the institutionalization of systems thinking in teacher training programs and increased emphasis on interdisciplinary STEM approaches. The relatively lower number of publications recorded in 2025 should be interpreted with caution, given the review's cut-off point in May 2025. The increase in master's theses during this period also reflects a rising research engagement among graduate students.

Types of Publications

Analysis of publication formats indicates a balanced distribution between journal articles (n = 12) and graduate theses (n = 10). This suggests that systems thinking is being explored both at the level of formal scholarly dissemination and within postgraduate research. Theses typically employed more comprehensive designs, including long-term instructional interventions and the development of original assessment tools. Journal articles were more likely to focus on pilot studies, conceptual discussions, or preliminary evaluations of teaching strategies (Figure 4).

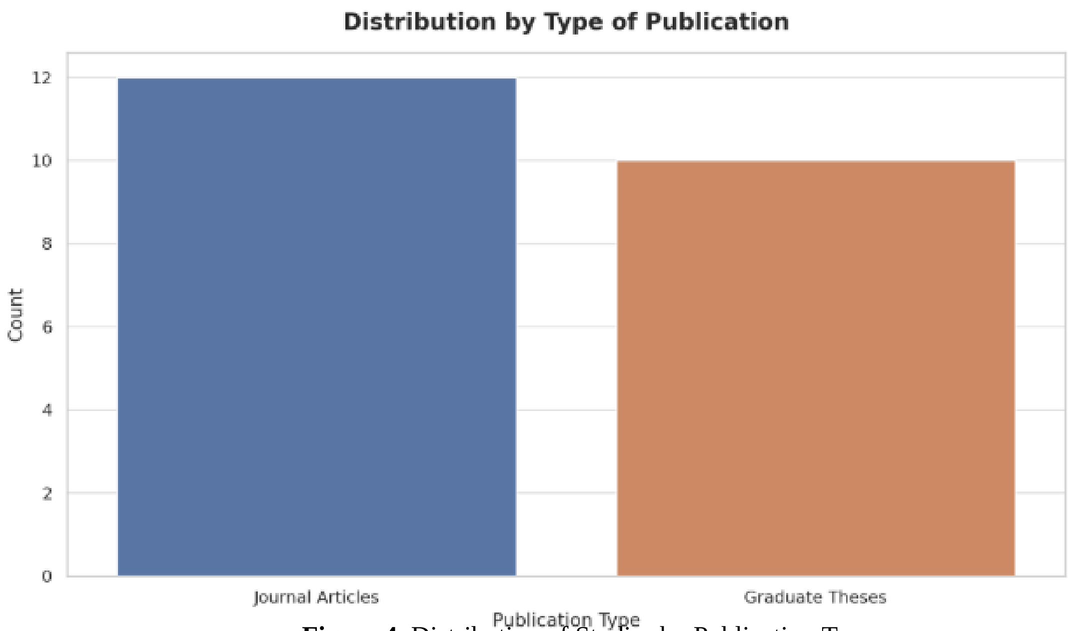

Figure 4. Distribution of Studies by Publication Type

As illustrated in Figure 4, of the 22 studies analyzed, 12 (approximately 55%) were journal articles, while 10 (45%) were master's or doctoral theses. The near-equilibrium between peer-reviewed publications and academic theses suggests that systems thinking is not only gaining traction among educational researchers but is also being actively explored within graduate-level academic programs.

Notably, the theses provided rich, practice-oriented insights—frequently involving instructional interventions, longitudinal data, and the use of student-generated materials such as concept maps, open-ended questions, and reflective narratives. In contrast, journal articles tended to focus on conceptual modeling, short-term experimental studies, or theory-driven content analyses. This contrast underscores the depth and methodological sophistication found in graduate research, while simultaneously highlighting the need for increased translation of thesis work into published scholarship accessible to broader academic and policy-making communities.

Participant Groups

Preservice science teachers (n = 8) and middle school students (n = 7) emerged as the most commonly studied populations. The concentration on these groups reflects a twofold strategy: equipping future educators with systems thinking competencies and embedding these skills at a formative stage of students' education. Fewer studies included high school students, in-service teachers, or primary learners, highlighting potential gaps in research diversity (Figure 5).

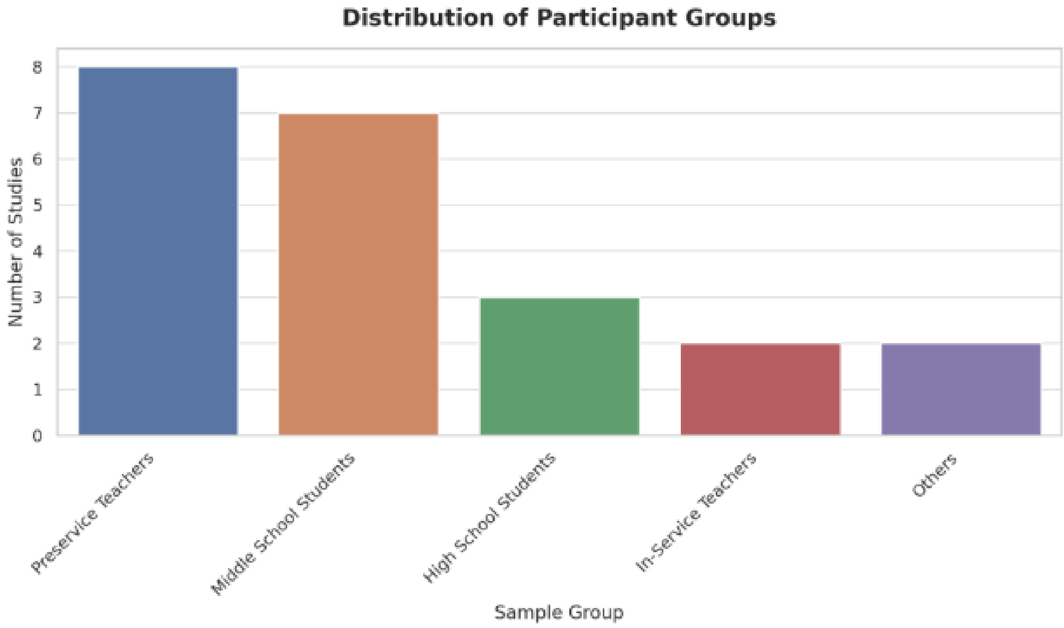

Figure 5. Distribution of Research Participants

As shown in Figure 5, the studies predominantly focused on preservice science teachers (n = 8) and middle school students (n = 7). This distribution reveals a dual emphasis on preparing future educators and introducing systems thinking concepts at early secondary education levels. High school students (n = 3), in-service teachers (n = 2), and other groups (n = 2) were comparatively underrepresented.

The focus on preservice teachers reflects the growing recognition of teacher education as a strategic entry point for pedagogical innovation. By equipping future educators with systems-oriented thinking tools, the long-term diffusion of such competencies into classrooms can be enhanced. However, the limited inclusion of in-service professionals and younger learners suggests missed opportunities for broader instructional transformation.

Methodological Approaches

The methodological landscape was dominated by qualitative research designs (n = 12), indicating an ongoing emphasis on exploratory work and theory building. Mixed-methods studies (n = 6) combined qualitative data with quantitative measures to evaluate student performance and conceptual understanding. Purely quantitative studies were relatively rare (n = 4), underscoring the need for greater empirical rigor and generalizability in future research efforts (Figure 6).

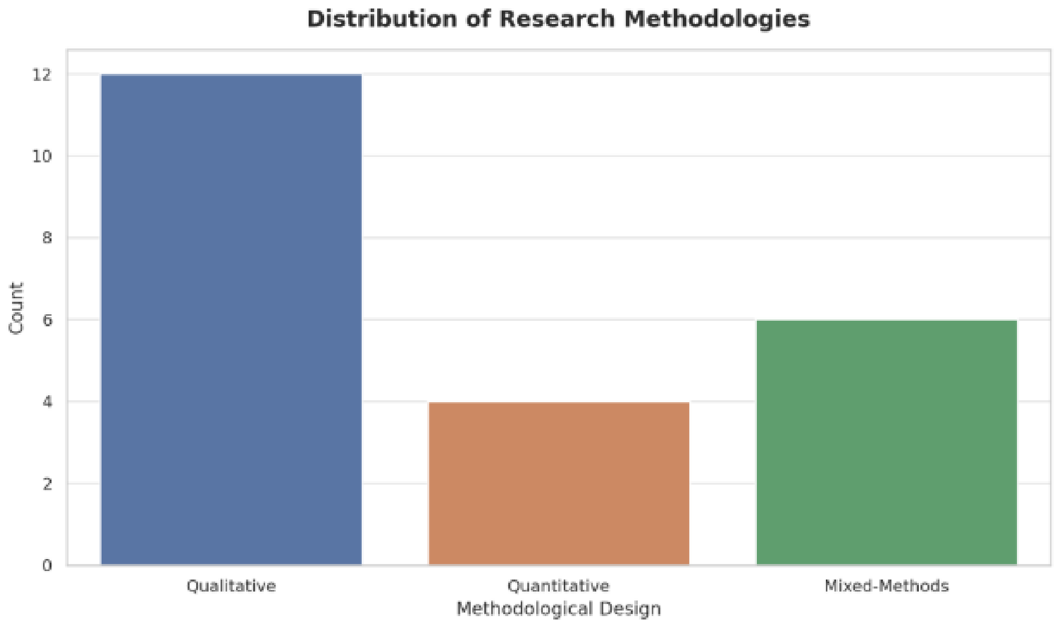

Figure 6. Distribution of Studies by Methodological Approach

Figure 6 illustrates the distribution of methodological approaches. Qualitative methods dominated the reviewed studies (n = 12), followed by mixed-methods (n = 6) and quantitative studies (n = 4). This pattern indicates that systems thinking research in Türkiye is currently situated within a predominantly exploratory and developmental phase.

Qualitative research designs often employed case studies, phenomenological analysis, or thematic coding to investigate students' cognitive processes, learning outcomes, or instructional strategies. Mixed-methods studies incorporated pre/post assessments, interviews, and document analysis to offer a more holistic evaluation of intervention effectiveness. Purely quantitative approaches remained limited and often lacked standardized instrumentation, pointing to a need for more validated tools and scalable models.

Data Collection Tools

The studies utilized a wide range of instruments to assess systems thinking competencies. Semi-structured interviews (n = 8), achievement tests (n = 6), and concept maps (n = 6) were the most frequently used tools. These instruments were particularly effective in capturing students' mental models, causal reasoning, and ability to represent complex systems. However, a limited number of studies employed standardized, validated tools, suggesting the need for further methodological refinement (Figure 7).

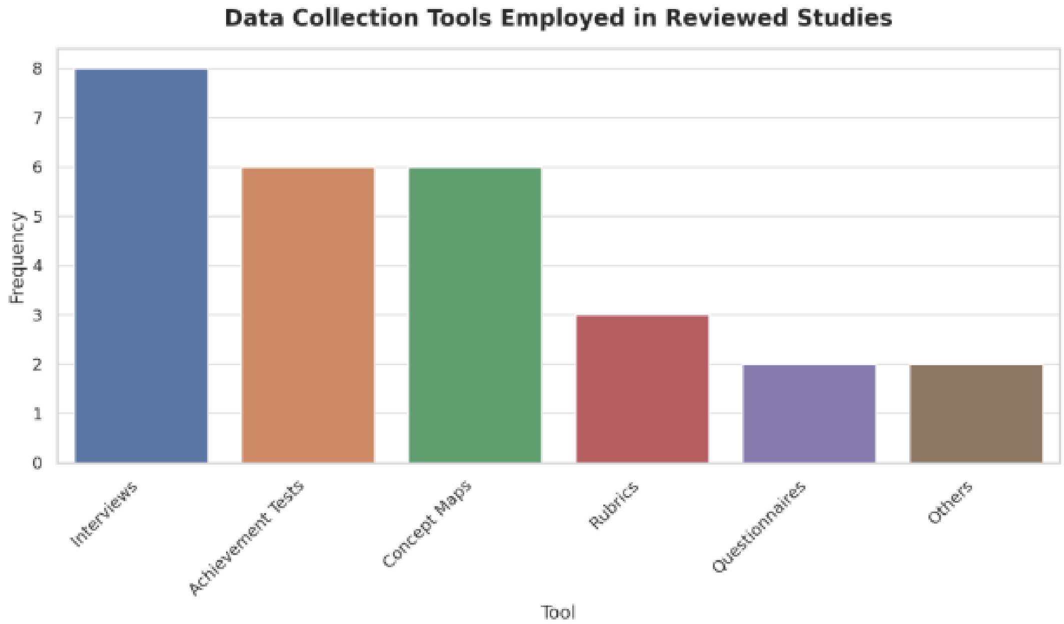

Figure 7. Instruments Used in Systems Thinking Studies

As depicted in Figure 7, the most commonly used data collection tools were semi-structured interviews (n = 8), achievement tests (n = 6), and concept maps (n = 6). These instruments were utilized to assess both conceptual understanding and systems thinking competencies such as causal reasoning, feedback recognition, and systemic integration.

Interviews provided rich, reflective data regarding participants' reasoning patterns and mental models. Concept maps were particularly effective in revealing how learners connect scientific phenomena within systemic frameworks. The limited use of validated scales and standard diagnostic tools remains a methodological limitation across many studies.

Thematic Focus

The majority of the reviewed literature centered on science education (n = 14) and explicit systems thinking skill development (n = 12). Other prominent themes included sustainability (n = 7), environmental education (n = 5), and STEM-related instruction (n = 3). These findings highlight a strong disciplinary alignment between systems thinking and the natural sciences, particularly in topics related to ecological cycles and environmental problem-solving. Nevertheless, areas such as ethics, curriculum literacy, and social systems remained underexplored (Figure 8).

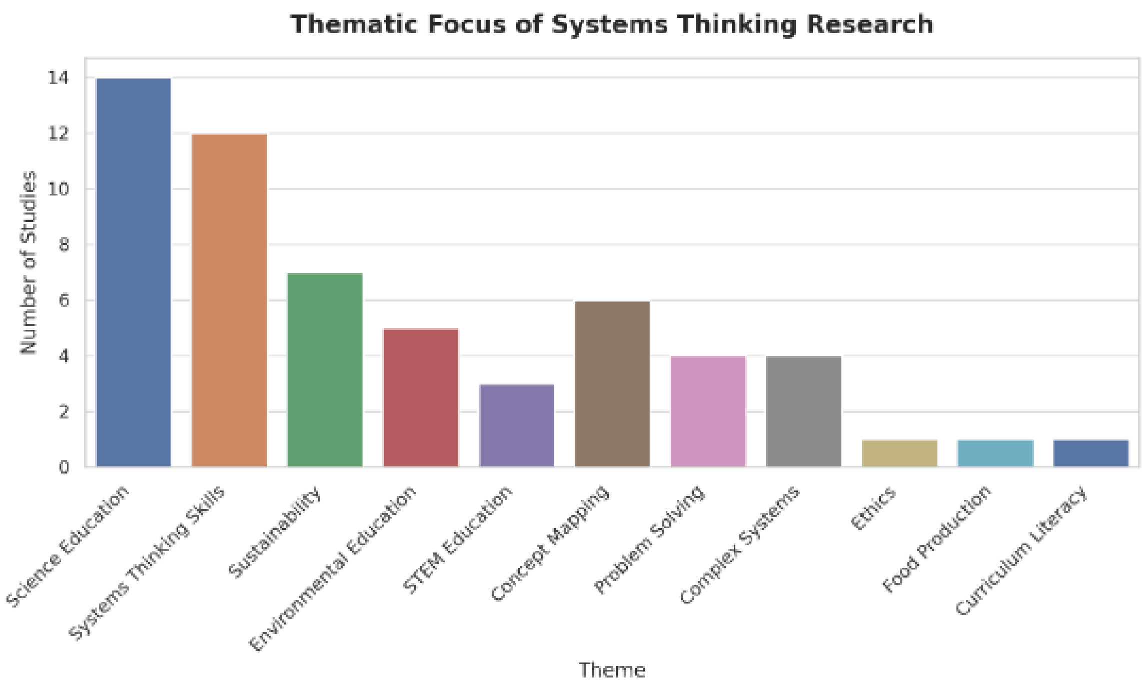

Figure 8. Thematic Distribution of Reviewed Studies

The thematic mapping in Figure 8 reveals that most studies were situated within science education (n = 14), with a secondary emphasis on directly measuring or fostering systems thinking skills (n = 12). Environmental education (n = 5), sustainability education (n = 7), and STEM integration (n = 3) emerged as frequent sub-themes.

These findings indicate that systems thinking is primarily contextualized within the natural sciences in Türkiye, especially ecology-related domains such as carbon cycles, food webs, and water systems. Less frequent themes—such as curriculum literacy, ethical reasoning, and digital systems—suggest future areas of development. Notably, the interdisciplinary potential of systems thinking remains underutilized in areas beyond environmental contexts.

Geographical Distribution

A regional analysis shows a concentration of studies in the Marmara Region (n = 8), followed by Central Anatolia (n = 4) and Eastern Anatolia (n = 3). The Mediterranean and Black Sea regions were significantly underrepresented, each contributing only one study. Six studies did not provide explicit information about their geographical context. The findings point to a regional imbalance in research production, likely linked to institutional capacities and funding opportunities (Figure 9).

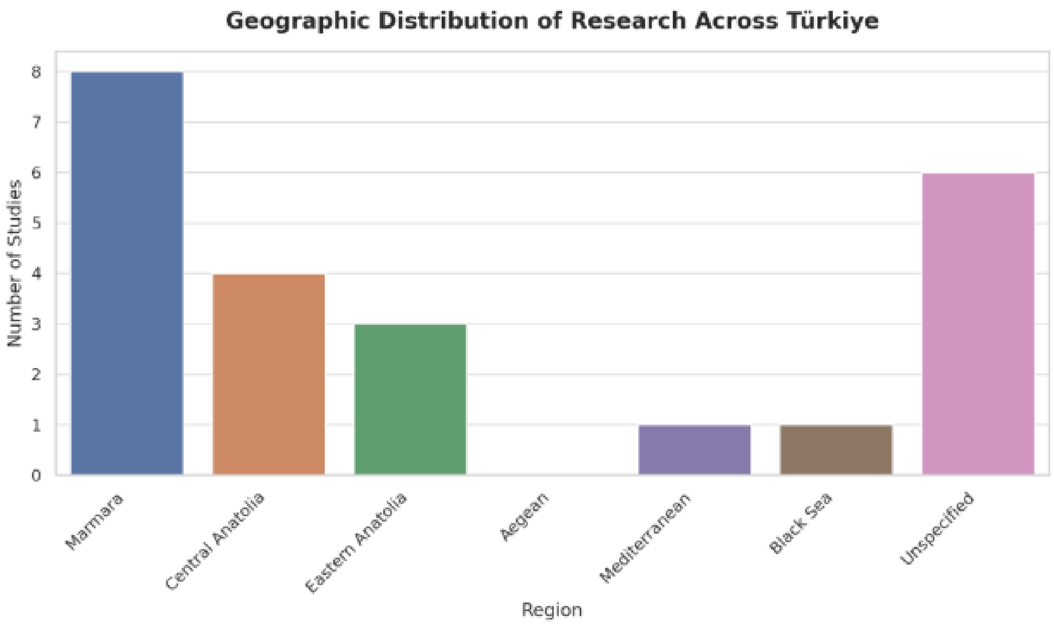

Figure 9. Regional Distribution of Systems Thinking Research

Figure 9 provides a geographical overview of where the studies were conducted or affiliated. The Marmara Region leads with eight studies, followed by Central Anatolia (n = 4) and Eastern Anatolia (n = 3). The Black Sea and Mediterranean regions were each represented by a single study, while six studies did not report geographic information.

The concentration in Marmara reflects the research output of well-established institutions in cities like Istanbul and Bursa. Conversely, the underrepresentation of other regions—especially those with distinct environmental or socio-cultural contexts—points to a regional imbalance in research attention. This gap highlights the need to promote systems thinking across diverse educational and geographical settings in Türkiye to ensure equity and contextual richness.

Conceptual Emphasis

A lexical analysis of study titles, abstracts, and keywords reveals that the most frequently used terms include "system," "thinking," "education," "teacher," "student," and "concept map." These keywords suggest that the literature is primarily concerned with classroom-level applications of systems thinking and its conceptual foundations. Keywords related to environmental content—such as "carbon," "cycle," and "water"—also feature prominently, reinforcing the ecological framing of many studies (Figure 10).

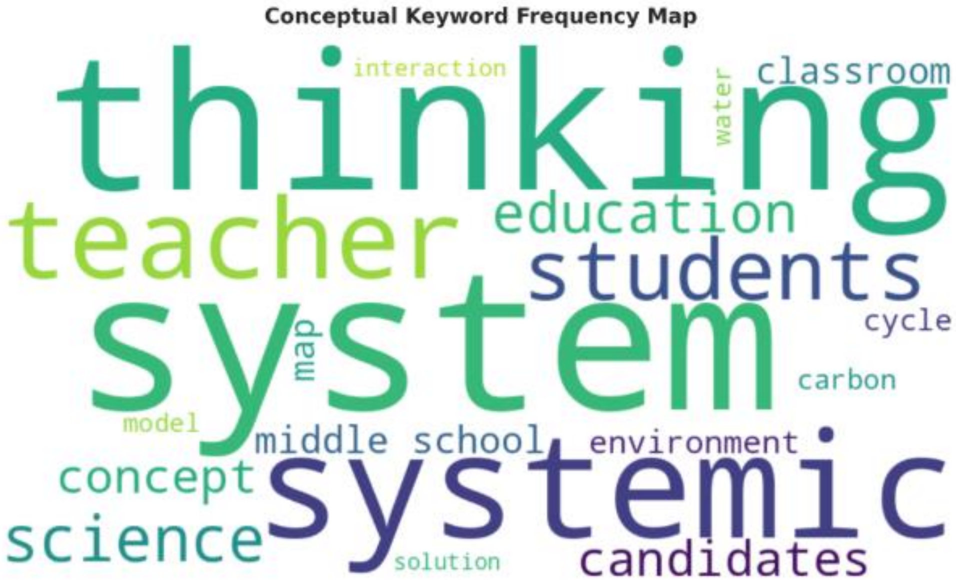

Figure 10. Keyword Frequency Word Cloud from Reviewed Studies

Figure 10 shows a word cloud generated from the titles, abstracts, and keywords of the included studies. The most frequently occurring terms—such as “system,” “thinking,” and “systemic”—clearly reflect the conceptual foundation of the reviewed literature. The presence of terms like “teacher,” “student,” “science,” “concept map,” and “environment” affirms the dominant pedagogical and disciplinary orientation of the field.

Additionally, frequent reference to concepts such as “cycle,” “carbon,” and “water” confirms the strong ecological framing of systems thinking research in Türkiye. Less frequently observed but equally important terms like “ethics,” “food production,” and “curriculum” suggest opportunities to expand research into new thematic areas. Overall, the keyword analysis confirms a conceptual maturity in the literature, while simultaneously revealing areas ripe for further exploration.

Together, these findings present a clear picture of the current state of systems thinking research in Turkish science education. While the literature has grown notably in both volume and sophistication since 2019, significant gaps remain in terms of methodological diversity, regional inclusivity, and the development of scalable, validated assessment instruments. These limitations, along with emerging trends, are further explored in the following discussion section.

CONCLUSION and DISCUSSION

This systematic review aimed to synthesize the current state of systems thinking research within Turkish science education over the past decade (2015–2025). The analysis of 22 empirical studies revealed both promising developments and persisting limitations in how systems thinking is conceptualized, implemented, and evaluated in Türkiye’s educational landscape. While the increasing frequency of publications, particularly since 2019, reflects a growing academic awareness of systems thinking, the findings also underscore significant structural and methodological challenges that must be addressed in order to align national research and practice with international standards.

The review reveals that the majority of studies adopted qualitative designs, primarily involving case studies, thematic analysis, or exploratory interviews. While these approaches provide valuable insight into learners' conceptual models and teachers' perceptions, they fall short in demonstrating the empirical effectiveness of systems thinking interventions at scale. The scarcity of quantitative and mixed-methods studies highlights a pressing need for more robust research designs that can produce generalizable evidence. For instance, none of the reviewed studies utilized large-scale randomized control trials, and only a few incorporated pre- and post-test measurements with validated instruments. This trend suggests that the evidence base for systems thinking in Türkiye is still in its formative stage, and largely anecdotal in nature.

Furthermore, systems thinking in Turkish science education remains thematically confined to environmental education, sustainability, and life cycles. While these are undoubtedly appropriate and globally relevant domains—given their inherent complexity and socio-ecological implications—the overconcentration in these areas may inadvertently limit the pedagogical scope of systems thinking. In international literature, systems thinking is increasingly recognized as a cross-cutting epistemological lens applicable to a range of domains, including genetics, thermodynamics, ecosystem modeling, planetary boundaries, and even socioscientific issues such as pandemics, climate justice, and energy transitions (Meadows, 2008; Wilensky & Resnick, 1999; Yoon et al., 2018). In comparison, Turkish research has yet to fully explore these integrative applications.

Another significant finding of the review pertains to the participant profiles. Most studies focused either on preservice science teachers or middle school students, with limited representation of high school students, in-service teachers, or younger learners. This narrow focus, while logical given the ease of access and curriculum alignment, restricts the understanding of how systems thinking develops longitudinally across different educational levels. Research from other countries demonstrates that systems thinking can and should be scaffolded progressively from early childhood through secondary education, using age-appropriate tools such as system maps, cause-effect chains, feedback loop diagrams, and digital simulations (Ben-Zvi Assaraf & Orion, 2010; Booth Sweeney & Sterman, 2007). In Türkiye, the absence of longitudinal or developmental research makes it difficult to identify appropriate entry points, curricular scaffolds, or age-graded competencies for systems thinking.

The regional distribution of studies is also uneven, with a majority of research concentrated in the Marmara and Central Anatolia regions. This pattern mirrors the geographic distribution of research infrastructure and graduate programs, but it also reveals a lack of national inclusivity. Given Türkiye’s ecological and cultural diversity, regional perspectives could provide valuable insight into how systems thinking is interpreted and practiced in different educational contexts. For example, rural schools in Eastern Anatolia may emphasize agricultural systems, while urban schools in the Aegean might focus on waste management or energy consumption systems. These local adaptations are largely absent from the current literature and represent a missed opportunity for context-sensitive pedagogy.

Teacher education emerges as a critical area requiring further development. Despite the conceptual importance of equipping educators with systems thinking competencies, few teacher training programs in Türkiye offer formal coursework or practicum experiences related to systems pedagogy. This stands in contrast to international trends, where systems thinking is integrated into teacher professional development and supported by digital modeling tools such as Insight Maker, Vensim, and Loopy (Kim & Lee, 2015; Plate, 2010). Without structured opportunities to develop these competencies, Turkish teachers may lack the confidence or capacity to meaningfully embed systems thinking in their science instruction.

Moreover, systems thinking in Türkiye is still largely understood as an instructional tool rather than a foundational epistemology. This instrumental framing reduces its potential to transform how science is taught and understood. Systems thinking, when adopted as an epistemological stance, encourages learners to shift from linear, fragmented reasoning to holistic, feedback-aware, and dynamic conceptualizations of natural and social phenomena. Such shifts are essential not only for disciplinary understanding but also for cultivating sustainability mindsets and transdisciplinary problem-solving skills—outcomes that are increasingly vital in the face of global challenges such as climate change, biodiversity loss, and public health crises (Sterman, 2000; Frank, 2021).

To address these challenges and move the field forward, several strategic recommendations emerge from this review:

Methodological Advancement

Researchers should adopt more rigorous designs, including longitudinal studies, intervention-based research, and validated assessment instruments that measure systems thinking performance, not just perceptions or self-reports. The adaptation of international tools such as the Systems Thinking Inventory (STI) or development of Türkiye-specific instruments should be prioritized.

Thematic Diversification

Future studies should expand their thematic scope beyond environmental education to include applications in physics, chemistry, health sciences, socio-technical systems, and ethical decision-making. This would help position systems thinking as a universal cognitive skill rather than a niche topic.

Teacher Preparation and Professional Development

Teacher education curricula must be updated to incorporate systems thinking principles explicitly. This includes not only theoretical knowledge but also hands-on experience with modeling tools, curriculum design, and interdisciplinary teaching strategies.

Technological Integration

The integration of digital tools that support system modeling and simulation can enhance both instruction and assessment. Collaborative platforms and serious games designed around system dynamics can foster active learning and deepen students' understanding of complex concepts.

Regional Equity in Research

Research funding and academic support should be directed toward underrepresented regions, enabling studies that reflect the diverse ecological, social, and educational contexts of Türkiye. Such decentralization would ensure that systems thinking is not limited to metropolitan or institutionally privileged settings.

Policy Alignment

The recent 2024 curriculum reform by the Ministry of National Education provides an important entry point for embedding systems thinking into national science education standards. However, successful implementation will require alignment between policy, teacher training, resource development, and assessment practices.

Global Collaboration

Establishing research networks with international institutions can help Turkish scholars access methodological innovations, digital tools, and comparative insights that enrich local research and practice. Participation in global initiatives such as the OECD's Future of Education and Skills 2030 or UNESCO's Education for Sustainable Development programs may also accelerate progress.

In conclusion, systems thinking holds significant potential to transform science education in Türkiye, equipping learners and educators with the tools to navigate complex, interconnected realities. The past decade has laid the conceptual foundation, but the next phase must be characterized by methodological rigor, curricular integration, teacher empowerment, and institutional commitment. By doing so, Türkiye can not only catch up with international developments but also contribute original insights to the global discourse on education for sustainability, complexity, and systems literacy.

SUGGESTIONS

Based on the findings and critical insights drawn from this systematic review, a set of concrete and research-informed suggestions can be offered to guide the future development of systems thinking in science education in Türkiye. These suggestions target multiple stakeholders, including researchers, teacher educators, curriculum designers, and policymakers, and are framed with the aim of fostering a more systemic, methodologically rigorous, and contextually inclusive approach to the integration of systems thinking across educational settings.

First and foremost, it is essential that future research moves beyond exploratory, small-scale qualitative studies toward more comprehensive and empirically robust designs. While qualitative methods have played a crucial role in laying the conceptual groundwork for systems thinking, the next phase of scholarship must focus on producing generalizable findings through mixed-methods and longitudinal approaches. Large-scale studies employing validated measurement tools can provide stronger evidence for the effectiveness of systems-based instruction and allow for cross-comparative analyses across student populations, disciplines, and learning environments.

Another important recommendation is the diversification of thematic contexts in which systems thinking is studied and applied. Although the emphasis on sustainability and environmental education is both timely and necessary, researchers and curriculum developers should seek to expand the scope of inquiry to include a broader range of science domains—such as physics, chemistry, health sciences, technological systems, and socioscientific issues. This will not only demonstrate the interdisciplinary versatility of systems thinking but also ensure that it is not misinterpreted as being relevant only to ecological topics.

Equally critical is the systematic integration of systems thinking into teacher education programs. As this review has shown, preservice teachers are frequently involved as research participants, yet few teacher education faculties offer structured modules or practical training in systems-based pedagogy. Universities and teacher training institutions should prioritize the inclusion of systems thinking within both theoretical coursework and practicum experiences. Providing preservice and in-service teachers with opportunities to engage in system modeling, feedback mapping, and scenario-based instruction will help ensure the meaningful translation of systems thinking into classroom practice.

In addition, the use of technological tools for teaching and assessing systems thinking should be significantly expanded. Simulation platforms, dynamic modeling software, and visual mapping tools—such as Insight Maker, Loopy, Stella, or Vensim—can facilitate students' understanding of complex systems while also supporting teachers in delivering interactive and student-centered lessons. Integrating such tools into science instruction and teacher education can greatly enhance the accessibility and engagement of systems-based learning, particularly in digital or blended environments.

A further recommendation involves addressing the regional disparities in research and implementation. Educational authorities, research funding bodies, and academic institutions should make deliberate efforts to promote systems thinking initiatives in underrepresented areas, particularly in the Eastern, Southeastern, and Black Sea regions. Localized research projects that explore the application of systems thinking in diverse cultural, ecological, and socioeconomic contexts can generate richer insights and help close the existing equity gaps in science education.

From a policy standpoint, the inclusion of systems thinking in the 2024 national science curriculum is a promising development. However, this curricular reform must be supported by coherent implementation strategies, including the development of instructional materials, assessment frameworks, and teacher professional development programs. Without systemic alignment between policy, pedagogy, and practice, there is a risk that systems thinking will remain a rhetorical goal rather than a transformative reality.

Finally, international collaboration should be encouraged to help Türkiye's educational research community engage with global best practices, innovations, and theoretical advancements in systems thinking. Participation in transnational research networks, conferences, and joint projects can facilitate capacity building and provide opportunities for benchmarking, adaptation, and contribution to the global discourse on systems literacy and sustainability education.

In sum, if supported through coordinated and sustained efforts across research, policy, and practice, systems thinking can serve as a powerful vehicle for cultivating scientific literacy, critical reasoning, and adaptive problem-solving in Turkish learners. The next decade presents an opportunity to build on the foundations outlined in this review and to realize the full potential of systems thinking as a transformative framework for science education in Türkiye.

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