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Bibliometric Analysis in Chemistry Education: Exploring System Thinking Skill in Water Treatment

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ABSTRACT

This study employs a bibliometric analysis approach to map the scientific literature related to chemistry education and systems thinking skills development in the context of water treatment. We used VOSviewer with the keyword "System AND Thinking", "Chemistry", and "Education" to support our database analysis from Scopus. The analysis examines key publications, influential authors, and emerging trends in the field, highlighting the growing importance of system thinking skills in addressing environmental challenges. By incorporating system thinking skills into educational practices, students can develop a holistic understanding of complex systems and their interdependencies. The findings emphasize the potential of such educational strategies to equip learners with the analytical tools necessary for solving real-world problems, such as designing sustainable water treatment solutions. This study offers insights into curriculum development and pedagogical approaches, advocating for the alignment of sustainability education with industry and societal needs.

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1. INTRODUCTION

In the 21st century, the world faces increasingly complex environmental challenges, such as water scarcity and pollution, which threaten not only ecosystems but also the survival of humans who depend on clean water resources (Mohammed *et al*., 2023; Bilad, 2017; Waqas *et al*., 2021; Khelassi-Sefaoui *et al*., 2021). These problems require solutions that are not only effective but also sustainable, given their wide-ranging and interconnected impacts (Solihah *et al*., 2024; Djirong *et al*., 2024; Kerans *et al*., 2024). In this context, systems thinking emerges as an innovative approach capable of offering a holistic framework for understanding and addressing such issues (Senge & Sterman, 1992). The application of this approach, particularly in water treatment technologies, has great potential to support the achievement of sustainability goals. However, to turn these scientific advances into practical and widely implementable solutions, a workforce with strong systems thinking skills is required to manage the complexities and interconnections within such systems.

Systems thinking, an approach that emphasizes understanding the interconnections and interdependencies within complex systems, is essential for addressing multifaceted environmental issues. In educational contexts, fostering systems thinking skills among students prepares them to tackle real-world challenges with a comprehensive and innovative mindset. Integrating molecular sustainability concepts into curricula offers a unique opportunity to develop these skills, enabling learners to bridge theoretical knowledge with practical applications (Michalopoulou *et al*., 2019; Eka & Pursitasari, 2021; Nelvarina *et al*., 2024).

This study conducted a bibliometric analysis to explore the state of research on sustainability and its relevance to education integrating with systems thinking skills, with a particular focus on water treatment applications. By analyzing trends, influential works, and emerging themes, this research aims to identify opportunities to incorporate molecular sustainability into educational practice. The findings highlight the importance of aligning sustainability education with industry needs, equipping students with the tools to meaningfully contribute to environmental problem-solving.

2. METHODS

This research combined a bibliometric analysis approach that was used to map the literature landscape and was followed by an in-depth literature review to explore key themes, identify gaps, and provide further insights into developments and future research directions. The analysis was supported by VOSviewer. Detailed information regarding the use and analysis of VOSviewer was reported elsewhere (Al Husaeni & Nandiyanto, 2022). The scope of the bibliometric analysis in this study consisted of scientific articles sourced from the Scopus database focusing on the keywords "System AND Thinking," "Chemistry," and "Education," spanning from 1986 to 2024. The data obtained from Scopus included: (i) documents by year; (ii) documents by author; (iii) documents by affiliation; (iv) documents by country; (v) documents by type; and (vi) documents by subject area.

Metadata collected through the Scopus database consisted of 263 scientific articles, which were then manually selected to ensure the completeness of the components required for the visualization analysis with VOSviewer. This selection process aimed to discard articles lacking complete information, such as year of publication, publisher, journal name, or those not written in English. Consequently, only publications meeting these criteria were included in the analysis to ensure the quality and relevance of the data. Once the metadata was selected and adjusted, the data meeting the criteria were exported as a .ris file. This .ris format allowed

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for the structured storage of bibliographic information, which was easily imported into bibliometric analysis software such as VOSviewer, CiteSpace, or Bibliometrics for further analysis. This process ensured that the data used in the research was properly formatted and ready for systematic analysis. VOSviewer was employed to create network visualizations of commonly used terms in a particular field.

In addition to creating network visualizations, VOSviewer was also used to analyze the evolution of a particular field based on the common terms identified. After opening VOSviewer, the exported data was loaded for further analysis. At this stage, the type of analysis to be performed was selected and conducted, such as co-authorship analysis, co-occurrence, citation analysis, or bibliographic merging, depending on the research objectives. Each of these types of analysis produced a network visualization illustrating the relationships between the elements being analyzed, such as the relationships between authors, articles, or keywords. Network maps (such as network and overlay visualizations) provided a visual representation of the patterns of relationships between elements after the VOSviewer analysis was completed. The color and size of the elements in the map indicated the intensity or frequency of the relationships between the analyzed elements. The results of these visualizations were used to identify emerging groups or clusters, which indicated dominant themes or topics within the emerging literature.

3. RESULTS AND DISCUSSION

Figure 1 shows the trend in the number of documents published per year based on data from Scopus related to research with a focus on "Systems AND Thinking," "Chemistry," and "Education" from 1986 to 2024. In **Figure 1**, it can be seen that the number of publications was relatively stable and low during the early period, from 1986 to around 2010. However, there is a slight sporadic increase in some years, such as 2004, indicating an initial interest in the topic. A significant increase was seen starting in 2017, which was followed by a sharp spike in 2019. The peak number of publications occurred in 2020, with more than 50 documents published. This can be attributed to the increasing global interest in systems thinking approaches in chemistry education, especially to support technological innovation and environmental sustainability, including in water treatment (Maryanti *et al*., 2022; Jebur, 2023; Makinde *et al*., 2024; Rasuman *et al*., 2024). The increase in research related to system thinking skills between 2017-2019 is likely to have a close relationship with the implementation of the 21st-century curriculum in many countries (Sopekan, 2024; Susilowati *et al*., 2023; Maryanti & Nandiyanto, 2021; Peter & Ogunlade, 2024). The 21st-century curriculum emphasizes the development of relevant skills to face global complex challenges, such as critical thinking, problem-solving, collaboration, and innovation, all of which can be accommodated through a systems thinking approach (Lestari, 2024; Misbah *et al*., 2022; Glushchenko, 2023; Molderez & Ceulemans, 2018). Some of the reasons why the 21st-century curriculum is driving increased research in this period are as follows:

(i) Emphasis on Systemic Thinking
The 21st-century curriculum promotes a more systematic, integrative, and interdisciplinary approach to learning, which enables learners to understand the relationship between different elements in a system. System thinking becomes the foundation for teaching students how to analyze and solve complex problems (Sopekan, 2024; Susilowati *et al*., 2023; Maryanti & Nandiyanto, 2021; Peter & Ogunlade, 2024).

(ii) Global and Sustainable Context
Global issues, such as climate change, water crisis, and environmental sustainability, have started to receive greater attention in this decade. System thinking is considered an

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important tool to analyze and solve these problems holistically, thus encouraging more research in education and its applications, including in water treatment (Mohammed, 2023).

(iii) Integration in Science Technology Engineering and Mathematics (STEM) Education
System thinking is an important part of STEM (Science, Technology, Engineering, and Mathematics) education in the 21st-century curriculum, especially in building students' skills in connecting chemistry concepts with the real world, such as water treatment and sustainability (Sholihah *et al*., 2024; Lestari *et al*., 2024).

(iv) Global policies and education standards
Some international organizations, such as UNESCO and OECD, began to encourage the integration of 21st-century skills in global education in this period. This push may be a catalyst for researchers to explore and develop systems thinking approaches in various educational contexts (Onia, 2022).

After 2020, the number of publications showed a decline but remained at a relatively high level compared to previous years. This decline may be due to external factors, such as the impact of the COVID-19 pandemic on research activities, or a shift in research focus towards more specific fields (Phanse, 2021). However, data from 2023 and 2024 show a stabilization with a positive trend, indicating that this topic remains relevant in the academic community.

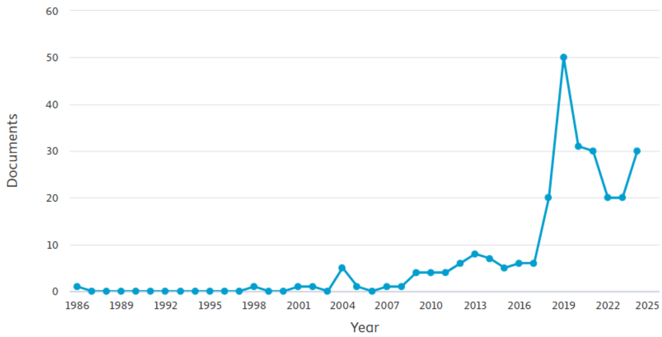

Figure 1. Trends in the number of documents published per year based on Scopus data (1986-2024) with a focus on "Systems AND Thinking," "Chemistry," and "Education".

Figure 2 shows the distribution of published document types based on data from Scopus. The majority of published documents are journal articles (58.2%), reflecting that research in this field is predominantly published in the form of scientific articles in peer-reviewed journals. This indicates a focus on disseminating key research results that are accessible to the academic community at large. The second largest document type was conference papers (22.1%), which demonstrates the important role of academic conferences as a forum for discussing and presenting new research in this field. Conferences are often the initial venue for the publication of new ideas before they are further developed into journal articles. Other documents included reviews (8.0%), indicating the need to summarize and analyze existing research to identify trends, gaps, and future opportunities. Meanwhile, book chapters (6.1%) indicate contributions in the form of more in-depth discussions or discussions in a broader context, such as a book or anthology. Other categories, such as editorials (1.1%), letters (0.8%), notes (0.4%), and short surveys (0.4%), show smaller but still important contributions in providing brief views, opinions, or surveys on a particular topic.

Figure 3 shows the distribution of documents by subject area in related research according to data from Scopus. Most of the documents are from the Social Sciences field (28.9%), indicating the dominance of social and educational approaches in this topic, especially regarding the implementation of systems thinking skills in educational contexts. The

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Chemistry field accounted for 22.0%, emphasizing the relevance of this topic in supporting innovation and teaching in the chemical sciences, particularly in technical applications such as water treatment. Social sciences and chemical sciences require systems thinking skills because the nature of the problems faced in these two fields tend to be complex, interrelated, and multidimensional (Ke *et al*., 2020; Celestino, 2023). In the social sciences, problems such as social inequality, cultural change, or educational challenges involve many variables that interact with each other. Systems thinking allows researchers and practitioners to analyze these relationships holistically, allowing them to thoroughly understand the root causes and impacts. This skill is also important in designing sustainable solutions, as it considers not only immediate impacts but also long-term consequences for society and the environment. For example, in education, systems thinking can help students understand the relationship between individuals, institutions, policies, and their impact on social life, preparing them to tackle global challenges such as urbanization, economic inequality, or climate change (Onat *et al*., 2017). On the other hand, chemistry also strongly requires systems thinking skills due to the nature of this science which often deals with complex systems. Chemical reactions do not stand alone but involve interactions between various components in a larger system, such as an industrial process, carbon cycle, or ecosystem. Systems thinking helps chemical scientists understand the relationships between these elements, so they can design more efficient and environmentally friendly processes. In global contexts, such as water treatment or resource management, systems thinking enables the development of sustainable chemical technologies to solve problems such as pollution, energy efficiency, and environmental sustainability. Therefore, systems thinking skills are not only relevant in laboratory research but also in the design of technologies capable of addressing increasingly pressing environmental challenges (York & Orgill, 2020; Hurst, 2020; Glissen *et al*., 2020; Gill & McCollum, 2024; Orgill *et al*., 2019).

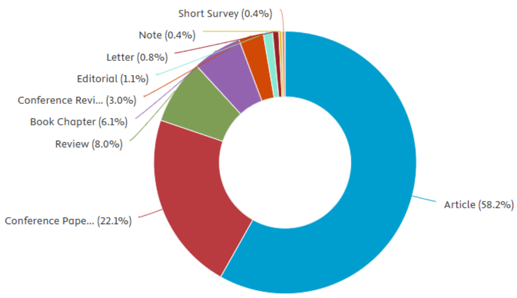

Figure 2. Distribution of published document types based on data from Scopus.

Computer Science (7.3%) and Physics and Astronomy (6.5%) also made significant contributions, demonstrating the involvement of technology and interdisciplinary approaches in developing systems thinking skills. In addition, fields such as Environmental Engineering (6.1%), Engineering (6.1%), and Chemical Engineering (3.3%) showed direct relevance to practical applications of these topics, particularly in the design and management of water treatment systems. Contributions from other fields, such as Health (2.8%), Biochemistry (2.4%), and Pharmacology (2.2%), highlighted the role of systems thinking skills in cross-disciplinary applications, including the health and pharmaceutical sectors. Other fields (12.4%) covered a range of topics that were not directly classified, but were nonetheless relevant in supporting cross-disciplinary discussions. The application of systems thinking skills is still limited in several fields such as chemical engineering, environmental engineering, physics, astronomy, and health compared to social sciences and chemistry. This is due to the different focus and priorities in the research approach in each field. Social sciences and

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chemistry are naturally more multidimensional and interdisciplinary in nature, so the application of systems thinking is a necessity to understand the complex interactions between various variables. In contrast, fields such as engineering or physics are often more focused on specific technical solutions, such as the development of certain tools, materials, or processes, which prioritize micro approaches rather than macro systems (Zhang *et al*., 2024; Shipley *et al*., 2017; Dziatkovskii *et al*., 2022). In addition, the research tradition in these fields still tends to be specialist and technical, so the adoption of holistic approaches such as systems thinking is still in its early stages. However, with increasing attention to global challenges such as sustainability and resource management, systems thinking approaches are expected to become increasingly relevant and widely adopted in these fields, especially through cross-disciplinary collaboration.

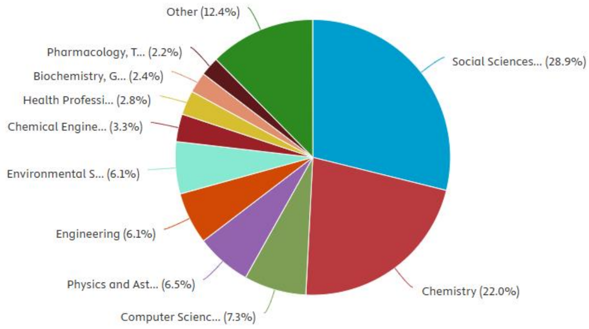

Figure 3. Distribution of documents by subject area in related research according to data from Scopus.

Figure 4 shows the distribution of the number of published documents by country or region related to research focused on "System AND Thinking," "Chemistry," and "Education." From **Figure 4**, the United States is the country with the highest number of publications, reaching more than 80 documents. This reflects the dominance of the United States in academic research in this field, supported by a strong research infrastructure, large funding, and extensive international collaboration. The second position is occupied by Indonesia, with a significant number of documents, indicating the increasing attention in Indonesia to topics such as chemistry education and systems thinking, which are relevant to local and global challenges, especially in the context of sustainability and 21st-century education. Countries such as Canada, the United Kingdom, Israel, and Germany also have significant contributions, each with publications in the range of 20 to 30 documents. These contributions indicate the importance of interdisciplinary research and the development of education systems in these countries. Australia, South Africa, Sweden, and Belgium are also seen to be active in publications, although with a smaller number of documents, indicating the contribution of various world regions to the development of literature in this field. This distribution reflects the global pattern in systems thinking research and chemistry education, with contributions dominated by developed countries, but balanced by important roles from developing countries such as Indonesia. This trend suggests greater opportunities for international collaboration, especially in addressing global challenges such as environmental sustainability and educational innovation.

Figure 5 shows a network map of the relationships between the most frequently occurring keywords. In this network map, it can be seen that the terms "chemistry education" and "systems thinking" are the main hubs (largest nodes) with strong connections to other keywords, such as "sustainable chemistry," "green chemistry," and "climate change." This indicates that the topic of chemistry education is closely related to the systems thinking

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approach, especially concerning sustainability and global issues. Smaller but significant nodes, such as “critical thinking skills,” “model,” and “experiment,” highlight the importance of critical thinking skills and the experimental process in systems-based teaching and learning. These keywords indicate a close relationship between experiment-based learning methods and the development of systems thinking skills in students. In addition, other clusters such as “physics,” “mathematics,” and “analysis” indicate interdisciplinary connections between chemistry education and other fields, especially in understanding and solving problems involving complex systems. These clusters show how systems thinking is applied in the broader context of STEM education. Keywords such as “sustainable development goal,” “global challenge,” and “collaboration” indicate the research focuses on the application of systems thinking to address global challenges, such as environmental sustainability and 21st-century education. This indicates that educational systems and curricula based on systems thinking are an important focus in building holistic solutions to complex problems (Spain, 2019; Elsawah *et al*., 2022; Pazicni & Flynn, 2019; Iqbal *et al*., 2022; Hyyppä *et al*., 2024). This network map illustrates how key concepts in chemistry education systems and systems thinking are interconnected, and how their application can support the development of skills relevant to global challenges. The connections between nodes reflect the multidisciplinary collaboration and holistic approach that is increasingly being developed in this research.

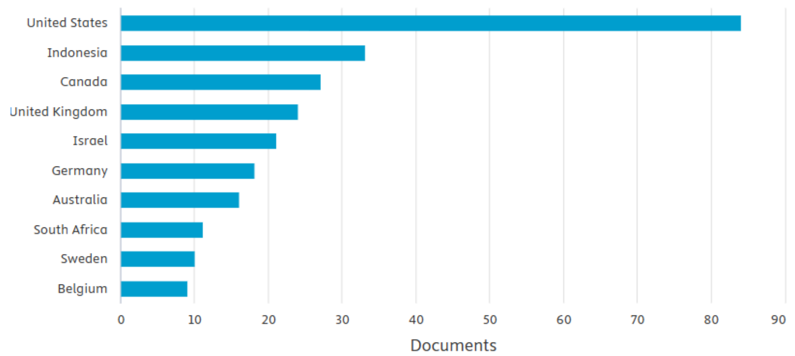

Figure 4. Distribution of the number of documents issued by country or region.

From **Figure 5**, although specific terms such as "water treatment" are not seen as the main node, there are several relevant terms that can be indirectly linked. Keywords such as "sustainable chemistry," "chemical process," "systems thinking," and "sustainable development goal" are closely related to the concept of water treatment, especially in the context of sustainability, for example: (i) "Sustainable chemistry" plays a role in the development of environmentally friendly water treatment processes by utilizing more efficient chemicals and minimizing waste; (ii) "Systems thinking" can be used to understand and integrate various aspects of a water treatment system, such as resource management, technology selection, and its impact on the environment; and (iii) "Global challenge" and "climate change" are often related to the need for sustainable water solutions, especially in facing water crises in various regions of the world. The systems thinking approach is very relevant in water treatment because it allows a holistic analysis of the various interacting components in the system. Water treatment systems involve many elements, such as natural resources, technology, regulations, and community needs, which influence each other. With systems thinking, water management can be designed to integrate technologies that are efficient, environmentally friendly, and appropriate to local needs. For example, this approach can help select treatment technologies that are not only effective in producing clean water but also consider their impact on the environment, such as carbon emissions from

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the energy used or chemical waste produced. In addition, systems thinking enables sustainable water management through efficient use of resources, waste-to-energy processing, and the use of renewable energy (Wan Rosely & Voulvoulis, 2023; McAlister *et al*., 2022; Polaine *et al*., 2022). This is also relevant in the context of global sustainability, such as addressing the water crisis and supporting sustainable development goals. This approach can be applied at various scales, from the design of urban systems that recycle wastewater to integrated management in rural areas that manage rainwater, domestic wastewater, and irrigation water. By understanding the relationships between elements in a water treatment system, systems thinking enables the creation of solutions that are effective, sustainable, and able to address future global challenges.

Figure 6 shows a temporal network map of the relationships between keywords in related research. The map includes dynamically connected keywords from 2017 to 2021, with color gradients reflecting time (from blue for older keywords to yellow for newer keywords). The terms “chemistry education” and “systems thinking” remain the main hubs with many connections to other keywords, indicating their central role in academic discussions. Newer terms such as “green chemistry,” “sustainable chemistry,” and “sustainable development goals” tend to appear in the yellow section, indicating the recent increased attention to sustainability issues. This reflects the shift in research focus from traditional chemistry education concepts to the application of systems thinking to global challenges such as sustainability and climate change. Meanwhile, nodes such as “critical thinking skills,” “analysis,” and “integration” show the interconnection between critical thinking skills and interdisciplinary approaches in STEM education. Terms such as “experiment,” “model,” and “physics” also highlight the importance of experiment-based teaching in integrating systems thinking skills with science education. Based on **Figure 6**, the following are suggestions for research that have the potential for novelty: (i) integration of systems thinking in Education for water treatment; (ii) green chemistry for sustainable water treatment systems; (iii) development of Interdisciplinary Models in STEM Education; (iv) connection between Chemistry Education and environmental sustainability; (v) analysis of the influence of systems understanding on social change; and (vi) exploration of new technologies in systems-based education.

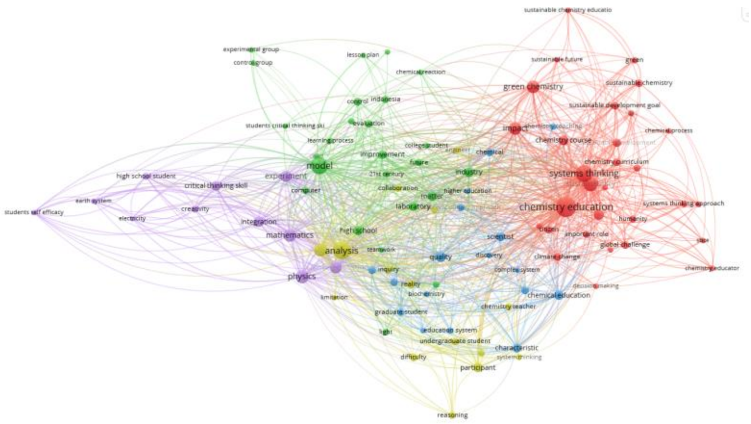

Figure 5. Network visualization of relationships between the most frequently occurring keywords.

Bibliometric analysis of systems thinking research in chemistry education, particularly in water treatment applications, provides important insights into trends and opportunities in this field (Nandiyanto *et al*., 2020; Santoso *et al*., 2022). The findings suggest that systems thinking is becoming an increasingly essential approach to addressing complex environmental

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challenges through innovative education. Integrating this approach into the education system has great potential to equip young people with the skills and knowledge needed to effectively address environmental issues (Wan Rosely & Voulvoulis, 2023; McAlister *et al*., 2022; Polaine *et al*., 2022).

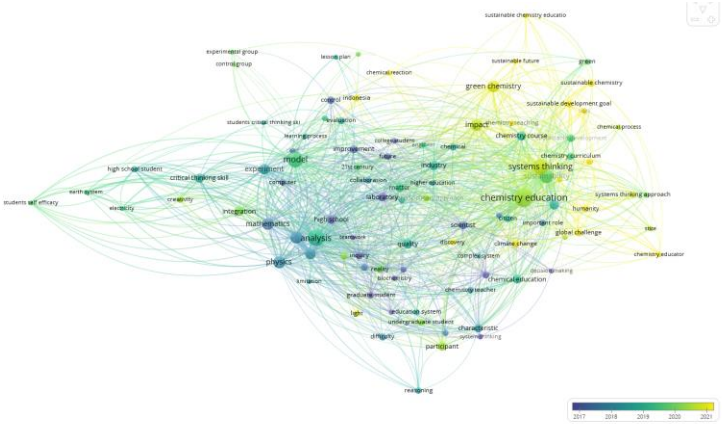

Figure 6. Overlay visualization of relationships between keywords in related research.

One of the key findings of this analysis is the significant increase in research linking chemistry education to systems thinking over the past two decades. This approach shows a transition from traditional educational models to more interdisciplinary teaching, where chemistry education focuses not only on fundamental chemistry concepts but also connects them to sustainability issues and real-world challenges such as the water crisis (Busta & Russo, 2020; Zoller & Scholz, 2004). For example, teaching using a project-based approach allows students to understand how chemical reactions, material properties, and physical principles can be applied in the design of water treatment systems. This not only enhances their understanding of chemistry concepts but also encourages them to think critically and holistically about how these technologies contribute to environmental sustainability (Wagiran *et al*., 2023; Wahyudi *et al*., 2024).

Furthermore, this approach also opens up opportunities to introduce students to concepts such as the life cycle of chemicals in environmental systems, the impact of chemical waste on ecosystems, and emission reduction strategies. In this way, students not only learn about sustainable chemistry (e.g., water treatment as a technology), but also understand the social, economic, and ecological contexts that surround it (York & Orgill, 2024; Dugan *et al*., 2022). Therefore, the integration of sustainability and water treatment principles into chemistry education provides a dual benefit: building students' technical competence while raising their awareness of the importance of a systems-based approach in solving global environmental challenges.

Studies have shown that the application of systems thinking in the curriculum can increase student engagement, critical thinking skills, and problem-solving skills, especially in the context of water treatment (York *et al*., 2019). One of the main findings of this analysis is that there has been a significant increase in research linking chemistry education to sustainable chemistry over the past two decades that focuses not only on fundamental chemical concepts (York & Orgill, 2024). By integrating sustainability principles into the STEM education curriculum, students are encouraged to understand how chemical reactions occur and increase their awareness of the relationship between technology and sustainability. This approach not only builds technical competency but also prepares students to think critically about the role of chemistry in solving global environmental challenges (Dziatkovskii *et al*., 2022).

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Pedagogical strategies such as project-based learning, case studies, and team collaboration have been shown to be effective in enhancing students' systems thinking skills. Through these strategies, students not only understand the theory but are also able to apply it in real situations, such as through internships or fieldwork at water treatment facilities. This approach also helps build practical and collaborative skills that are essential for working in interdisciplinary teams in the future (Wagiran *et al*., 2023; Wahyudi *et al*., 2024).

However, there are several challenges in integrating systems thinking into chemistry education, such as the lack of training for teachers in the concepts of sustainability and systems thinking, and the limited resources available to teach these concepts in the context of water treatment. These challenges also provide opportunities for innovation, for example through the development of teacher training programs that focus on systems thinking approaches and the provision of teaching materials that connect chemical theory with real-world applications in water treatment.

The results of this study indicate that the integration of systems thinking in chemistry education is essential to building a generation of learners who can understand environmental challenges comprehensively and seek sustainable solutions. Future research and curriculum development needs to focus more on strengthening teacher training, providing learning resources, and developing practice-oriented educational programs. Thus, chemistry education can play a central role in addressing environmental problems, especially those related to water treatment.

4. CONCLUSION

This bibliometric analysis shows that research linking chemistry education, systems thinking, and sustainable chemistry has grown significantly in the last two decades. This reflects the increasing attention to global challenges such as environmental sustainability and water crisis, and the importance of education in equipping future generations with relevant skills to address these issues. Research on chemistry education and systems thinking skills shows significant growth, especially in a global context that requires a holistic approach to address 21st-century challenges. The United States leads the research contribution, followed by developing countries such as Indonesia. The majority of publications are journal and conference articles, with a focus on social sciences and chemistry as the main areas. From the visualization trend analysis, it is apparent that topics such as "systems thinking," "chemistry education," and "sustainable chemistry" are interconnected, with a focus on the development of innovative technologies, such as environmentally friendly chemical-based water treatment systems. Furthermore, this study identifies the importance of an interdisciplinary approach in integrating sustainability concepts into STEM education, which supports students in understanding the complex relationships between technological, environmental, and social aspects. Future research should focus on implementing and evaluating this framework in educational settings to assess its impact on student learning outcomes and its broader implications for sustainability education. By leveraging molecular sustainability as a cornerstone of curriculum design, educators and policymakers can contribute meaningfully to building a sustainable and resilient future.

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6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

7. REFERENCES

Bilad, M.R. (2017). Membrane bioreactor for domestic wastewater treatment: Principles, challanges and future research directions. *Indonesian Journal of Science and Technology*, *2*(1), 97-123.

Busta, L., and Russo, S. E. (2020). Enhancing interdisciplinary and systems thinking with an integrative plant chemistry module applied in diverse undergraduate course settings. *Journal of Chemical Education*, *97*(12), 4406-4413.

Celestino, T. (2023). High school sustainable and green chemistry: Historical–epistemological and pedagogical considerations. *Sustainable Chemistry*, *4*(3), 304-320.

Djirong, A., Jayadi, K., Abduh, A., Mutolib, A., Mustofa, R.F., and Rahmat, A. (2024). Assessment of student awareness and application of eco-friendly curriculum and technologies in Indonesian higher education for supporting sustainable development goals (SDGs): A case study on environmental challenges. *Indonesian Journal of Science and Technology*, *9*(3), 657-678.

Dugan, K. E., Mosyjowski, E. A., Daly, S. R., and Lattuca, L. R. (2022). Systems thinking assessments in engineering: A systematic literature review. *Systems Research and Behavioral Science*, *39*(4), 840-866.

Dziatkovskii, A., Hryneuski, U., Krylova, A., and Loy, A. C. M. (2022). Chronological progress of blockchain in science, technology, engineering and math (STEM): A systematic analysis for emerging future directions. *Sustainability*, *14*(19), 12074.

Ekamilasari, E., and Pursitasari, I.D. (2021). Students' critical thinking skills and sustainability awareness in science learning for implementation education for sustainable development. *Indonesian Journal of Multidiciplinary Research*, *1*(1), 121-124.

Elsawah, S., Ho, A. T. L., and Ryan, M. J. (2022). Teaching systems thinking in higher education. *Informs Transactions on Education*, *22*(2), 66-102.

Gilissen, M. G., Knippels, M. C. P., and van Joolingen, W. R. (2020). Bringing systems thinking into the classroom. *International Journal of Science Education*, *42*(8), 1253-1280.

Gill, T., and McCollum, B. (2024). Identifying, rating, and categorizing elements of systems thinking in chemistry education. *Journal of Chemical Education*, *101*(8), 2976-2988.

Glushchenko, V.V. (2023). Development of the design thinking paradigm in the context of the transition to a new technological order. *Indonesian Journal of Multidiciplinary Research*, *3*(1), 117-130.

Hurst, G. A. (2020). Systems thinking approaches for international green chemistry education. *Current Opinion in Green and Sustainable Chemistry*, *21*, 93-97.

Hyyppä, I., Rasa, T., and Laherto, A. (2024). Fostering students' systems thinking through futures education. *Frontline Learning Research*, *12*(2), 27-50.

Iqbal, A. M., Khan, A. S., Abdullah, J., Kulathuramaiyer, N., and Senin, A. A. (2022). Blended system thinking approach to strengthen the education and training in university-industry research collaboration. *Technology Analysis & Strategic Management*, *34*(4), 447-460.

Jebur, T.K. (2023). Greening the internet of things: A comprehensive review of sustainable IOT solutions from an educational perspective. *Indonesian Journal of Educational Research and Technology*, *3*(3), 247-256.

Ke, L., Sadler, T. D., Zangori, L., and Friedrichsen, P. J. (2020). Students' perceptions of socio-scientific issue-based learning and their appropriation of epistemic tools for systems thinking. *International Journal of Science Education*, *42*(8), 1339-1361.

Kerans, G., Sanjaya, Y., Liliasari, L., Pamungkas, J., and Ate, G., Y. (2024). Effect of substrate and water on cultivation of Sumba seaworm (nyale) and experimental practicum design for improving critical and creative thinking skills of prospective science teacher in biology and supporting sustainable development goals (SDGs). *ASEAN Journal of Science and Engineering*, *4*(3), 383-404.

Khelassi-Sefaoui, A., Khechekhouche, A., Daouadji, M.Z.D., and Idrici, H. (2021). Physico-chemical investigation of wastewater from the Sebdou-Tlemcen textile complex North-West Algeria. *Indonesian Journal of Science and Technology*, *6*(2), 361-370.

Lestari, D.A., Suwarma, I.R., and Suhendi, E. (2024). Feasibility analysis of the development of STEM-based physics e-book with self-regulated learning on global warming topics. *Indonesian Journal of Teaching in Science*, *4*(1), 1-10.

Lestari, I.S. (2024). Bibliometric analysis using VOSviewer with Publish or Perish of identifying local legends through project-based learning for critical thinking skills in English. *ASEAN Journal of Community Service and Education*, *3*(2), 69-78.

Makinde, S.O., Ajani, Y.A., and Abdulrahman, M.R. (2024). Smart learning as transformative impact of technology: A paradigm for accomplishing sustainable development goals (SDGs) in education. *Indonesian Journal of Educational Research and Technology*, *4*(3), 213-224.

Maryanti, R., and Nandiyanto, A.B.D. (2021). Curriculum development in science education in vocational school. *ASEAN Journal of Science and Engineering Education*, *2*(1), 151-156.

Maryanti, R., Rahayu, N.I., Muktiarni, M., Al Husaeni, D.F., Hufad, A., Sunardi, S., and Nandiyanto, A.B.D. (2022). Sustainable development goals (SDGs) in science education: Definition, literature review, and bibliometric analysis. *Journal of Engineering, Science and Technology*, *17*(Special issue of ICMScE), 161-181.

McAlister, M. M., Zhang, Q., Annis, J., Schweitzer, R. W., Guidotti, S., and Mihelcic, J. R. (2022). Systems thinking for effective interventions in global environmental health. *Environmental Science & Technology*, *56*(2), 732-738.

Michalopoulou, E., Shallcross, D. E., Atkins, E., Tierney, A., Norman, N. C., Preist, C., and Ninos, I. (2019). The end of simple problems: repositioning chemistry in higher education and society using a systems thinking approach and the united nations' sustainable development goals as a framework. *Journal of Chemical Education*, *96*(12), 2825-2835.

Misbah, M., Hamidah, I., Sriyati, S., and Samsudin, A. (2022). A bibliometric analysis: research trend of critical thinking in science education. *Journal of Engineering, Science and Technology*, *17*(Special issue of ICMScE), 118-126

Mohammed, S.R. (2023). Quantitative analysis of the problems and prospects of the Nigerian industrial sector in the 21st century. *ASEAN Journal for Science Education*, *2*(1), 55-56.

Molderez, I., and Ceulemans, K. (2018). The power of art to foster systems thinking, one of the key competencies of education for sustainable development. *Journal of Cleaner Production*, *186*, 758-770.

Nandiyanto, A.B.D., Biddinika, M.K., and Triawan, F. (2020). How bibliographic dataset portrays decreasing number of scientific publication from Indonesia. *Indonesian Journal of Science and Technology*, *5*(1), 154-175.

Nelvarina, N., Agustina, T.W., and Solikha, M. (2024). Can the inquiry learning model improve students' system thinking skills?. *ASEAN Journal for Science Education*, *3*(1), 55-64.

Onat, N. C., Kucukvar, M., Halog, A., and Cloutier, S. (2017). Systems thinking for life cycle sustainability assessment: A review of recent developments, applications, and future perspectives. *Sustainability*, *9*(5), 706.

Onia, S.I. (2022). Education policy of Sudan and utilization of the mobile device (iPad) technology: Opportunities and challenges. *Indonesian Journal of Educational Research and Technology*, *2*(3), 205-212.

Orgill, M., York, S., and MacKellar, J. (2019). Introduction to systems thinking for the chemistry education community. *Journal of Chemical Education*, *96*(12), 2720-2729.

Pazicni, S., and Flynn, A. B. (2019). Systems thinking in chemistry education: Theoretical challenges and opportunities. *Journal of Chemical Education*, *96*(12), 2752-2763.

Peter, J.A., and Ogunlade, O.O. (2024). Connectivism theory in education and its applications to curriculum and instruction. *ASEAN Journal of Educational Research and Technology*, *3*(3), 215-222.

Phanse, S. (2021). The online education impact on students during covid- 19 pandemic. *Indonesian Journal of Teaching in Science*, *1*(2), 137-140.

Polaine, X. K., Dawson, R., Walsh, C. L., Amezaga, J., Peña-Varón, M., Lee, C., and Rao, S. (2022). Systems thinking for water security. *Civil Engineering and Environmental Systems*, *39*(3), 205-223.

Rasuman, M.A., Nandi, N., Astari, A.J., and Ashie, A.B. (2024). Trends and networks in education for sustainable development (ESD): A bibliometric analysis using vosviewer. *Indonesian Journal of Multidiciplinary Research*, *4*(1), 109-126.

Santoso, B., Hikmawan, T., and Imaniyati, N. (2022). Management information systems: Bibliometric analysis and its effect on decision making. *Indonesian Journal of Science and Technology*, *7*(3), 583-602.

Senge, P. M., and Sterman, J. D. (1992). Systems thinking and organizational learning: Acting locally and thinking globally in the organization of the future. *European Journal of Operational Research*, *59*(1), 137-150.

DOI: http://dx.doi.org/10.17509/xxxx.xxxx
p- ISSN 2775-8419 e- ISSN 2775-8427

Shipley, T. F., McConnell, D., McNeal, K. S., Petcovic, H. L., and John, K. E. S. (2017). Transdisciplinary science education research and practice: Opportunities for GER in a developing STEM discipline-based education research alliance (DBER-A). *Journal of Geoscience Education*, *65*(4), 354-362.

Solihah, P.A., Kaniawati, I., Samsudin, A., and Riandi, R. (2024). Prototype of greenhouse effect for improving problem-solving skills in science, technology, engineering, and mathematics (STEM)-education for sustainable development (ESD): Literature review, bibliometric, and experiment. *Indonesian Journal of Science and Technology*, *9*(1), 163-190.

Sopekan, O.S. (2024). Implementing peace education concepts in early childhood curriculum: A tool for addressing violence and promoting sustainable development in Nigeria. *Indonesian Journal of Multidiciplinary Research*, *4*(2), 259-266.

Spain, S. (2019). Systems thinking applied to curriculum and pedagogy: A review of the literature. *Curriculum Perspectives*, *39*, 135-145.

Susilowati, N.I., Liliawati, W., and Rusdiana, D. (2023). Science process skills test instruments in the new indonesian curriculum (merdeka): Physics subject in renewable energy topic. *Indonesian Journal of Teaching in Science*, *3*(2), 121-132.

Wagiran, W., Mujiyono, M., Setiadi, B.R., Wibowo, Y.E., Surahmanto, F., Agata, D.A., and Areeprasert, C. (2023). Temperature distribution in bio stove using saw dust: An integrated project-based learning. *Indonesian Journal of Science and Technology*, *8*(1), 127-140

Wahyudi, W., Setiawan, A., Suhandi, A., and Samsudin, A. (2024). Technology-supported project-based learning: Trends, review and future research in science, technology and engineering education. *ASEAN Journal of Science and Engineering*, *4*(1), 119-126.

Wan Rosely, W. I. H., and Voulvoulis, N. (2023). Systems thinking for the sustainability transformation of urban water systems. *Critical Reviews in Environmental Science and Technology*, *53*(11), 1127-1147.

Waqas, S., Bilad, M.R., and Man, Z.B. (2021). Performance and energy consumption evaluation of rotating biological contactor for domestic wastewater treatment. *Indonesian Journal of Science and Technology*, *6*(1), 101-112.

York, S., and Orgill, M. (2020). ChEMIST table: a tool for designing or modifying instruction for a systems thinking approach in chemistry education. *Journal of Chemical Education*, *97*(8), 2114-2129.

York, S., Lavi, R., Dori, Y. J., and Orgill, M. (2019). Applications of systems thinking in STEM education. *Journal of Chemical Education*, *96*(12), 2742-2751.

Zhang, Y., Feijoo-Garcia, M. A., Gu, Y., Popescu, V., Benes, B., and Magana, A. J. (2024). Virtual and augmented reality in science, technology, engineering, and mathematics (stem) education: An umbrella review. *Information*, *15*(9), 515.

Zoller, U., and Scholz, R. W. (2004). The HOCS paradigm shift from disciplinary knowledge (LOCS)-to interdisciplinary evaluative, system thinking (HOCS): What should it take in science-technology-environment-society oriented courses, curricula and assessment?. *Water Science and Technology*, *49*(8), 27-36.

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