JKPK (JURNAL KIMIA DAN PENDIDIKAN KIMIA), Vol. 8, No.2, 2023 pp. 248-265
Chemistry Education Study Program, Universitas Sebelas Maret ISSN 2503-4146
https://jurnal.uns.ac.id/jkpk ISSN 2503-4154 (online)

A BIBLIOMETRIC ANALYSIS OF PUBLICATIONS ON SYSTEMS THINKING IN CHEMISTRY EDUCATION USING VOSVIEWER

Banu Kisworo[1,4], Ahmad Mudzakir[2*], Liliasari[2], Anna Permanasari[3]

[1]Doctorate Program of Science Education, Faculty of Mathematics and Science Education, Universitas Pendidikan Indonesia, Indonesia.
[2]Department of Chemistry Education, Faculty of Mathematics and Science Education, Universitas Pendidikan Indonesia, Indonesia.
[3]School of Post Graduate Studies, Universitas Pakuan Bogor, Indonesia.
[4]Department of Chemistry Education, Faculty of Teacher Training and Education, Universitas Muhammadiyah Cirebon, Indonesia.

ARTICLE INFO

Keywords:
Bibliometric analysis;
Chemistry Education;
Systems thinking;
VOSviewer

Article History:
Received: 2023-07-21
Accepted: 2023-08-18
Published: 2023-08-31

**Corresponding Author*
Email:mudzakir.kimia@upi.edu
oi:10.20961/jkpk.v8i2.76988

ABSTRACT

This study utilizes a bibliometric approach along with computational mapping analysis. This study employs a bibliometric approach, complemented by computational mapping using VOSviewer, to explore systems thinking research in chemistry education. The primary goal is to identify key research themes and trends in this field. The initial step involved searching for articles with keywords like "systems thinking" and "chemistry education" using the Publish or Perish software and Google Scholar database. This yielded 922 articles, which were carefully selected based on specific criteria. The comprehensive analysis included co-authorship, co-citation, co-occurrence, cluster, and content analysis using VOSviewer. The quantitative analysis highlights the significance of publications related to systems thinking in chemistry education and broader educational contexts. Over the past decade, prominent themes emerged, including sustainability education, design thinking, outcomes assessment, critical systems, climate change, and more. Qualitative insights further emphasize the relevance of understanding systems thinking in chemistry education, influencing pedagogical approaches and research initiatives. This research aims to provide valuable insights for researchers, educators, and practitioners in the chemistry education field. This study offers a roadmap for future developments by delineating prevalent themes and trends. Understanding the challenges and opportunities in systems thinking research within chemistry education can contribute to enhancing teaching methods and shaping research agendas. This analysis provides a comprehensive overview of the evolving landscape of systems thinking in chemistry education.

How to cite: B. Kisworo, A. Mudzakir, Liliasari, A. Permanasari, "A Bibliometric Analysis of Publications on Systems Thinking in Chemistry Education using Vosviewer," *JKPK (Jurnal Kimia dan Pendidikan Kimia)*, vol. 8,no.2, pp. 248-265, 2023. http://dx.doi.org/10.20961/jkpk.v8i2.76988

INTRODUCTION

Systems thinking has become a dominant concern among chemistry educators and chemists in recent years [1]. Systems thinking is needed as an approach that not only conveys concepts understanding a different component but also involves a systemic process that forms a concept learned by a pre-service chemistry teacher and how each component and process of other components influences each other to form a process [2]. Someone who systems thinking will be able to identify the components of the system, understand the relationships between components, explore and understand the emerging properties of these components, and analyze and synthesize the components of a phenomenon in a broader context [3]. Although much research on system thinking has been conducted in biological systems [4], earth systems [2], and health sciences [5], the application of systems thinking to educational chemistry still needs to be improved [6].

Systems thinking is the ability to identify system components, understand the relationships between components, explore and understand the emerging properties of these components, and analyze and synthesize the components of a phenomenon in a broader context [3]. Chemistry education, especially at the education level of pre-service chemistry teachers, requires understanding the molecular basis of sustainability. The systems thinking framework in chemistry education can serve as a bridge, facilitating the integration of knowledge concerning the molecular realm with the sustainability of the planet and its social systems. This alignment corresponds with the objectives of Education for Sustainable Development (ESD) within the domain of chemistry education. Including sustainable development themes in chemistry learning signifies a pedagogical endeavor aimed at future generations. Specifically, it emphasizes education focused on conserving natural resources and the environment through the principles of green chemistry. This integration enhances students' comprehension of the intricate connections between chemical processes and ecological equilibrium and instills a profound responsibility for preserving the planet's delicate balance. By integrating sustainability concepts into chemistry education, learners are positioned to emerge as conscientious custodians of the environment. This strategic integration equips them with the capacity to tackle real-world challenges adeptly, leveraging informed decision-making and innovative problem-solving.

Recognizing systems thinking in chemistry education is necessary for pre-service chemistry teachers to move knowledge in chemistry learning that was previously limited only to chemical reactions and processes into a more holistic understanding. The main activities of chemistry involve analysis, synthesis, and transformation of materials, but have not paid attention to the revealed aspects of studying chemistry for human, social, and environmental welfare. Overcoming violence requires attention to the material base of society, and a new paradigm for chemical practice is needed. Chemistry education, especially in college and high school courses, must emphasize an understanding of molecular basis sustainability. To increase this understanding, a systems thinking framework is needed in chemistry education to integrate world molecular knowledge with the sustainability of the earth and social systems [7]. Therefore, thinking systems is an important skill in learning chemistry [8].

To discover the development of system thinking research in chemistry education, one analytical technique is bibliometric analysis. Bibliometric analysis is a form of meta-analysis of research data that can help researchers review bibliographic content and analyze citations from journal articles and other research articles. The bibliometric analysis used in this study uses modern technology that can collect information, database management, and statistics by combining the VOS Viewer software. VOSviewer was chosen in this study because of its ability to display bibliometric data in an easy-to-understand visual form. Besides that, VOSviewer provides various visualization features in bibliometric analysis, such as network visualization, overlay visualization, and density visualization.

There have been many studies on bibliometric analysis, including bibliometric analysis in economics [9–11], E-Learning [12], Corporate Social Responsibility and Corporate Social Performance [13], bibliometric analysis in chemistry research [14–17] and chemical engineering [18,19], Special Needs Education [20], and Educational Research [21]. Various bibliometric studies show that systems thinking in chemistry education is a research topic that has continued to develop in recent years, which is worthy of further research to understand the evolution of research in scientific disciplines. The bibliometric analysis that has been conducted by previous researchers who analyzed 626 articles from the Scopus and Web of Science (WoS) databases showed that systems thinking has been a rapidly growing topic from 1991 - 2018 and is of interest to academics, practitioners, government, military and researchers in various domains including, engineering, systems, management, Education, Health, and others [22]. However, studies that researchers have conducted identify that the application of systems thinking in chemistry education has not been fully analyzed, including emerging trends, internal relationships between articles, the evolution of research, and hot topics related to this research using the Google Scholar database. Therefore, this research is presented by considering these reasons and filling in the gaps of previous research. Through this bibliometric analysis, it aims to provide a literature review to analyze the literature related to the topic of systems thinking in chemistry education. The novelty obtained from this research includes providing opportunities and challenges in applying systems thinking in chemistry education. This research is expected to contribute to the presentation of quantitative data and qualitative analysis for evolution and recent trends in the application of systems thinking in chemistry learning as a reference for further research.

METHODS

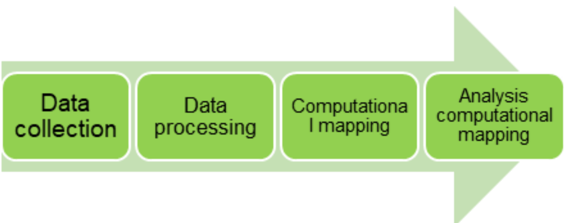

Figure 1. The Structure of The Research Stages

The article data used in this study is based on research articles published in Google Scholar-indexed journals. We selected Google Scholar in this study because the Google Scholar database is open source. A reference management application obtains Publish or

Perish (PoP) research data. The research was conducted through several stages, as shown in Figure 1 [23].

1. Data Collection

Collection of publication data using publish or perish application to search for articles on Google Scholar. This search was specific to 'journals,' using the keywords 'systems thinking' OR 'chemistry education,' and was limited to 2013 to 2022. Data collection steps should include inclusion and exclusion criteria, as shown in Figure 2.

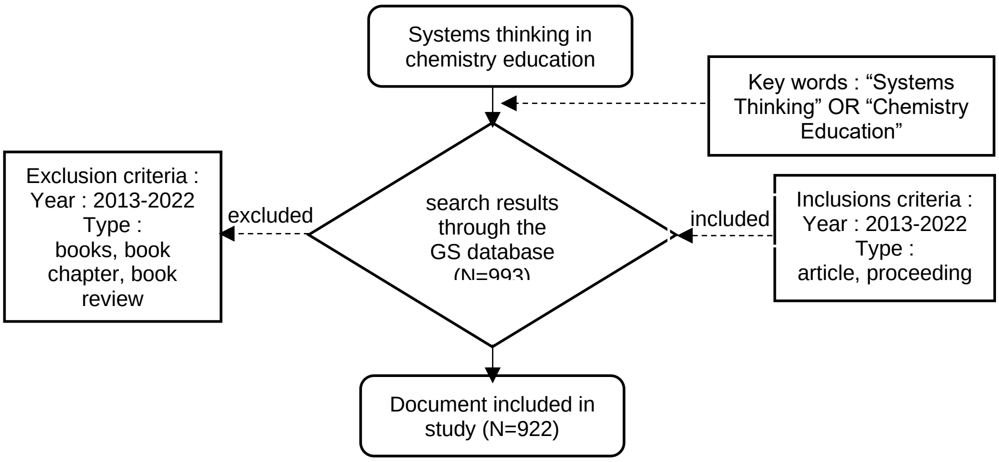

Figure 2. Literature Data Collection Techniques

The article search utilizing the keywords "Systems Thinking" OR "Chemistry Education" initially yielded 993 articles based on publication type or proceedings. Articles from 2013 to 2022 were considered to establish inclusion criteria, encompassing journals and proceedings. A refined dataset of 922 articles was acquired after excluding 71 book-form publications as they needed to meet the criteria for inclusion.

The data organization process used Microsoft Excel to format the initial search results into comma-separated values (.csv). This compilation encompassed crucial article details, such as paper titles, author identities, and affiliations. Furthermore, Microsoft Excel facilitated manipulating bibliometric data derived from the collected articles. The next step involved a meticulous filtration process, wherein pertinent articles were extracted from the Google Scholar database. It's worth noting that the dataset solely comprised journal articles, with books, book reviews, and book chapters being excluded. The inclusion of articles was contingent upon their alignment with the research's thematic focus, specifically 'systems thinking' OR 'chemistry education.' Through this rigorous selection process, a total of 922 articles were identified as relevant to the scope of the research.

2. Computational mapping

It uses the VOSviewer application for computational mapping analysis of bibliometric publication data. VOSviewer is used because it works efficiently with large data sets and provides a variety of visuals, including network, overlay, and density visualization.

3. Analysis of computational mapping results

Analyze and interpret the results of computational mapping visualization, including network, overlay, and density visualization.The article data search on Publish or Perish filters publications using the keywords "systems thinking" OR "chemistry education" based on the need for the publication title. The papers used were published between the years of 2013 and 2022. All data were obtained in June 2023. Articles that have been collected and match the analysis criteria of this study are then exported into a comma-separated value format (*.csv). VOSviewer can also be used to visualize and evaluate trends using bibliometric maps. The article data from the source database is then mapped. VOSviewer is used to create 3 variations of mapping publications: network visualization, density visualization, and network-based overlay visualization (co-citation) between existing items. When creating a bibliometric map, the keyword frequency is set to be found at least 3 times. As a result, 146 less relevant terms and keywords were removed. Based on data tracking through published or perish reference management applications from the Google Scholar database, 926 data articles were obtained that met the inclusion criteria. The data is in the form of article metadata consisting of the author's name, title, year, journal name, publisher, and number of citations. To ensure no repeated article data, you can check the terms menu in Vosviewer and output the same article data.

RESULTS AND DISCUSSION

1. Publication data search results

System thinking research article documents obtained from the Google Scholar database and then exported to CSV format, inputted, and analyzed with VOSViewer. The minimum threshold sets the minimum number of words that appear so that they can be presented in a folder. In this study, the number of words that appear at least three times so that the appropriate keywords and the number of occurrences of 3 times or more are included in the mapping.

Before the refinement, the search results obtained 926 articles through the Google Scholar database. After sorting based on the suitability of the type of publication, relevant topics, and the range, from 2013 to 2022, 4 article data were discarded. So, the total of articles used is 922 articles on systems thinking. The number of citations of all articles used in this study was 72,567, the number of citations per year was 7,256.70, the number of citations per article was 78.37, the average author of the articles used was 2.81, all articles had an average -index is 115, and g-index is 193. The researcher conducted a targeted sorting process, focusing on articles that held the utmost relevance to the intersection of systems thinking and chemistry education. This involved selecting articles that specifically explored the application of systems thinking in chemistry education and possessed the highest citation scores. The top 20 articles, distinguished by their citation counts, were tabulated to yield the outcomes presented in Table 1.

Table 1. Systems Thinking in Chemistry Education Publication Data

No	Authors	Title	Year	Cites	Refs
1	SA Matlin, G Mehta, H Hopf, A Krief	One-world chemistry and systems thinking	2016	173	[24]
2	MK Orgill, S York, J MacKellar	Introduction to systems thinking for the chemistry education community	2019	147	[25]
3	PG Mahaffy, A Krief, H Hopf, G Mehta	Reorienting chemistry education through systems thinking	2018	138	[26]
4	E Saxton, R Burns, S Holveck, S Kelley, D Prince	A common measurement system for K-12 STEM education: Adopting an educational evaluation methodology that elevates theoretical foundations and systems	2014	138	[27]
5	KM Jegstad, AT Sinnes	Chemistry teaching for the future: A model for secondary chemistry education for sustainable development	2015	111	[28]
6	S York, R Lavi, YJ Dori, MK Orgill	Applications of systems thinking in STEM education	2019	108	[29]
7	PG Mahaffy, SA Matlin, TA Holme, J MacKellar	Systems thinking for education about the molecular basis of sustainability	2019	103	[30]
8	S Nagarajan, T Overton	Promoting systems thinking using project-and problem-based learning	2019	79	[31]
9	M Reynolds, C Blackmore, R Ison, R Shah	The role of systems thinking in the practice of implementing sustainable development goals	2018	68	[32]
10	PG Mahaffy, SA Matlin, JM Whalen	Integrating the molecular basis of sustainability into general chemistry through systems thinking	2019	64	[7]
11	KB Aubrecht, M Bourgeois, EJ Brush	Integrating green chemistry in the curriculum: Building student skills in systems thinking, safety, and sustainability	2019	56	[33]
12	T Vachliotis, K Salta, C Tzougraki	Meaningful understanding and systems thinking in organic chemistry: Validating measurement and exploring relationships	2014	52	[34]
13	PG Mahaffy, EJ Brush, JA Haack, FM Ho	*Journal of Chemical Education* Call for Papers—Special Issue on Reimagining Chemistry Education: Systems Thinking and Green and Sustainable Chemistry	2018	45	[35]
14	TD Lee, M Gail Jones, K Chesnutt	Teaching systems thinking in the context of the water cycle	2019	43	[36]
15	GA Hurst	Systems thinking approaches for international green chemistry education	2020	42	[37]
16	S Pazicni, AB Flynn	Systems thinking in chemistry education: Theoretical challenges and opportunities	2019	38	[38]
17	DJC Constable, C Jiménez-González	Navigating complexity using systems thinking in chemistry, with implications for chemistry education	2019	38	[39]
18	AB Flynn, MK Orgill, FM Ho, S York	Future directions for systems thinking in chemistry education: Putting the pieces together	2019	36	[40]
19	V Talanquer	Some insights into assessing chemical systems thinking	2019	35	[41]
20	S York, MK Orgill	ChEMIST table: a tool for designing or modifying instruction for a systems thinking approach in chemistry education	2020	30	[42]

2. Research development of systems thinking and chemistry education

Figure 3 showed the development of systems thinking and chemistry education research published in Google Scholar-indexed journals. Based on the data shown in Figure 3, it can be seen that the total number of studies on systems thinking and chemistry education as a whole is 922 articles from 2013-2022. In 2013, there were 108 articles.

In 2014, there were 154 articles. In 2015, there were 115 articles. In 2016, there were 95; in 2017, 113 and 127. In 2019, there were 95 rules; in 2020, there were 82; in 2021, there were 27; and in 2022, there were 6 articles. The number of publications shows that research on systems thinking in chemistry education is rarely reviewed yearly, especially in the last 10 years (2013-2022). Its development fluctuated in certain years due to unpredictable changes in research trends because it adjusted to the conditions of the environmental, social, and technological systems that were developing at that time. However, when it is realized that all systems are interrelated and influence each other, they return to research on systems thinking. This is why recent research on systems thinking has increased again.

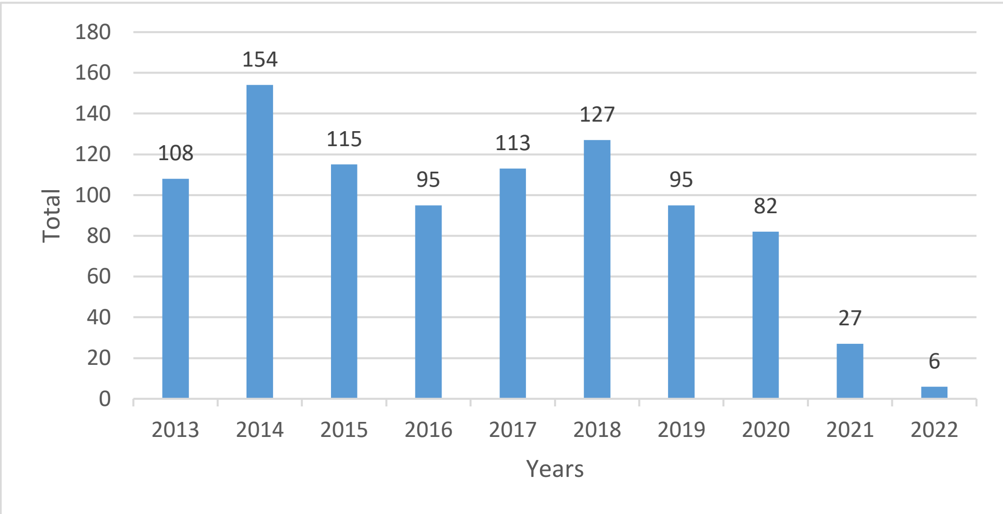

Figure 3. Level of development in systems thinking research and chemistry education

Figure 3 shows that research on system thinking and chemistry education increased from 2013 to 2014. This increase can be seen from the number of publications in 2013 of 108 publications to 2014 of, 154 publications. The trajectory of systems thinking research within chemistry education reveals certain patterns over the years. An observable decline occurred between 2015 and 2016, reflected in the publication count of 115 articles in 2015, which subsequently diminished to 95 articles in 2016. However, this trend was followed by a resurgence in 2017 and 2018, with publication counts reaching 113 and 127 articles, respectively. A contrasting pattern emerged in the subsequent four years, showcasing a decrease in publications from 2019 to 2022. Specifically, there were 95 articles published in 2019, 82 in 2020, 27 in 2021, and a mere 6 in 2022. These fluctuations indicate a fluctuating popularity of systems thinking research intertwined with chemistry education. The recent decline in interest in systems thinking research within chemistry education is particularly noteworthy.

As previously explained, there has been a decline in publications conducting systems thinking research in recent years—several factors, including the low cause of this.The researcher's interest is because, looking at the results of the track record of previous research, it is also not so high that it affects subsequent research. Another factor that influences the decline in systems thinking research is that most researchers only study according to their field background without linking it to aspects of other fields. So, that research has its scope. In 2016, world policies through the United Nations are scheduled to have principles of sustainable development goals in the world so that there is a need for linkages between systems, technological development, society, environment, and people's welfare. Systems thinking is needed to link between these system lines; therefore, systems thinking research began to show an increase from 2016 to 2018, as shown in Figure 2. The decline in systems thinking research occurred again from 2019 to 2022 due to a shift in research orientation, mainly related to world health, economics, and information technology problems, because in 2019, the world was hit by the COVID-19 outbreak. Research focuses on strengthening the health system in controlling COVID-19 [43], economic recovery, and improving communication information technology through network-based applications due to social restrictions.

However, as seen in Table 1, research on systems thinking in chemistry education has increased in 2019. This data is based on the top 20 rankings of the most citations researching systems thinking in chemistry education. This can happen as explained earlier that chemistry education has an important role in supporting education sustainable development programs that are strengthened by students' systems thinking skills. Therefore, the opportunities and challenges ahead for implementing systems thinking to achieve sustainable development goals are very open for researchers to conduct.

3. System thinking and chemistry education topic area visualization using VOSviewer

Computational mapping is performed on the article data. VOSviewer is used in computational mapping. From the computational mapping results found, 146 items were found. Each item was found to be related to systems thinking in chemistry education in data mapping and divided into 9 clusters, including (1). Cluster 1 consists of 31 items marked in red; the 31 items are ability, activity, assessment, case study, chemical, classroom, comparison, and complex. Context, course, definition, effort, environment, general chemistry, impact, inquiry, interaction, interest, intervention, motivation, organic chemistry, paper, .PCK, pedagogical content knowledge, performance, process, relevance, risk, synthesis, teacher, view. (2) Cluster 2 consists of 30 items and is marked in green; the 30 items are analysis, chemical kinetics, chemical reaction, chemistry, concept, conceptual understanding, content, curriculum, group, influence, investigation, map, misconception, model, nature, organization, PBL, problem, qualitative study, question, range, reaction, researcher, solution, structure, student, students understanding, study, task, understanding. (3) Cluster 3 consists of 21 items and is marked in blue; the 21 items are approach, change, chemistry education community, complex system, complexity, covid, critical system, future, insight, issue, lesson, literature, mechanism, overview, pandemic, science, society, system, systems approach, systems perspective, work. (4) Cluster 4 consists of 17 items and is marked in yellow; the 17 items are chemistry education research, collaboration, competency, concept map, focus, importance, knowledge, laboratory, learning, meaningful learning, order, practice, research, skill, strategy, teaching, thinking. (5) Cluster 5 consists of 15 items marked in purple; the 15 items are climate change, competence, dimension, education, esd, experience, framework, implementation, outcome, role, SDGs, sustainable development, sustainable development goal, systematic reviews, and systems thinking. (6) Cluster 6 consists of 10 items marked in sky blue; the 10 items are aspects, building, challenge, chemical education, chemistry education, communication technology, green chemistry, higher education, opportunity, and science education. (7) Cluster 7 consists of 10 items marked in orange; the 10 items are application, article, conceptual framework, decision, evaluation, field, methodology, system dynamic, systems theory, and theory. (8) Cluster 8 consists of 7 items marked in brown; the 7 items are case, perspective, school, school leadership, sustainability, sustainability education, and system. (9) Cluster 9 consists of 5 items marked in pink; the 5 items are design thinking, development, engineering, relationship, and technology.

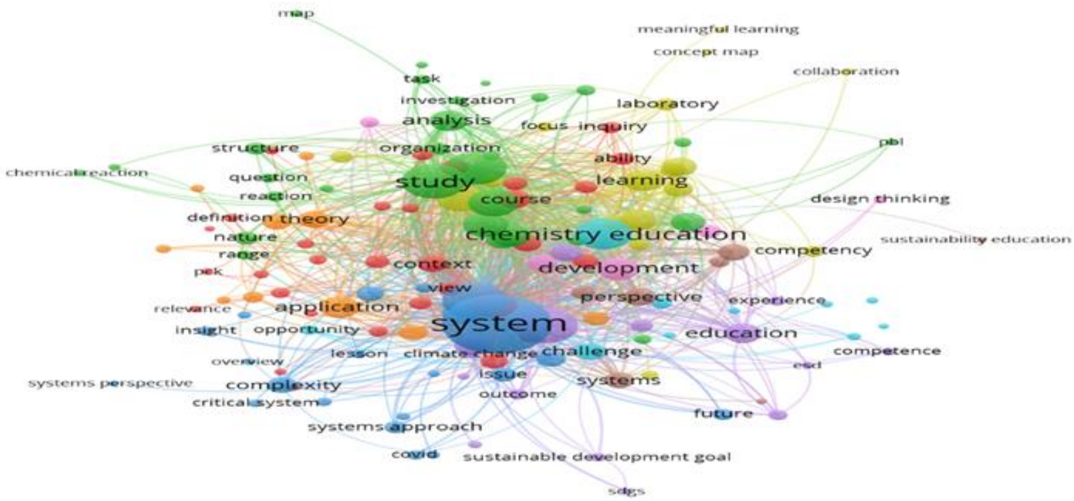

Figure 4. Network visualization of systems thinking in chemistry education keyword

The relationship between different terms is visually depicted within individual clusters [23]. Each term is labeled using colored circles, with the circle's size denoting the frequency of that particular term's occurrence. A larger circle indicates a higher occurrence frequency in both the title and abstract. The mapping visualization in this study encompasses three key components: network visualization (refer to Figure 4), density visualization (refer to Figure 5), and overlay visualization (refer to Figure 6).

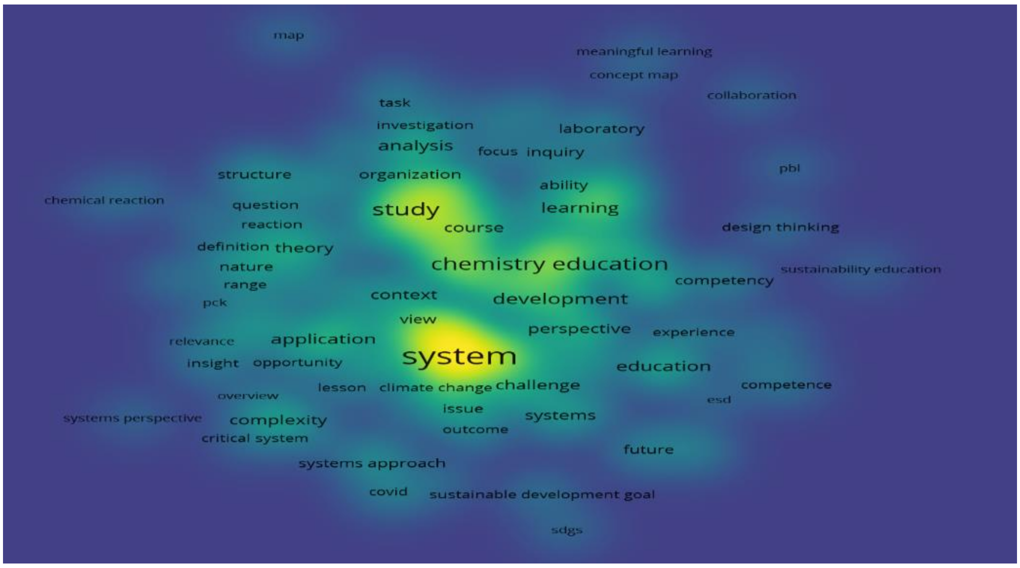

Figure 5. Density visualization of systems thinking in chemistry education

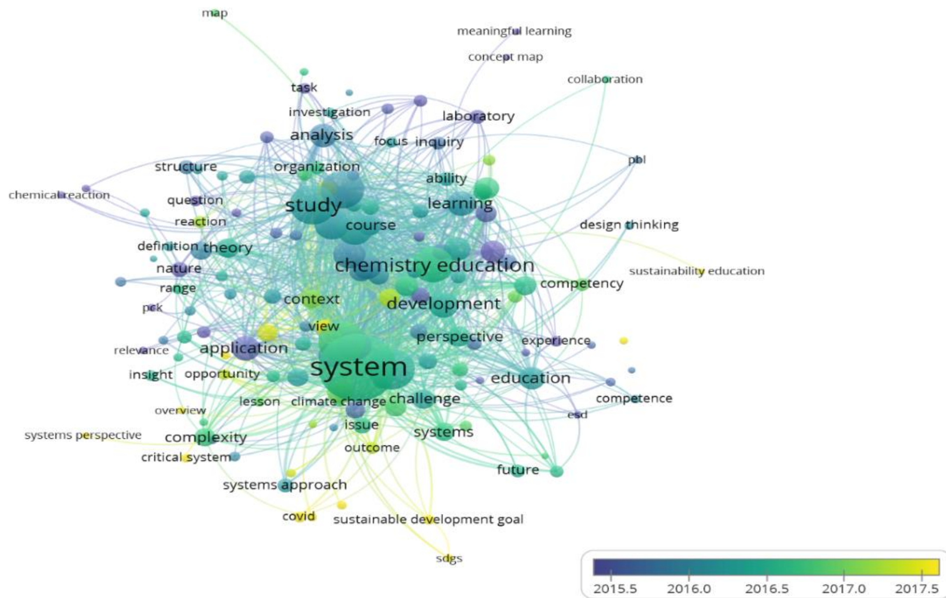

Figure 6. Overlay visualization of systems thinking in chemistry education keyword

Figure 4 illustrates the interrelationships among terms in a connected network [44]. The clusters in Figure 4 represent frequently researched terms associated with the research theme of systems thinking and chemistry education. The network visualization reveals distinct clusters, separating systems thinking research and chemistry education into two fields. Specifically, "systems thinking" resides in cluster 5, encompassing 120 links, a link strength of 739, and 177 occurrences (refer to Figure 7). Similarly, "chemistry education" occupies cluster 6, comprising 110 links, a link strength 550, and 129 occurrences (refer to Figure 8). Notably, the term "systems thinking" is not exclusively confined to chemistry education; rather, a connection between the two terms is evident in the interconnected network (refer to Figure 7).

The second term is chemistry education, which is included in cluster 6 with 110 links, a total strength of 550 links, and 129 occurrences (see Figure 8). Meanwhile, the term system thinking is not found in chemistry education, but the two terms have a connection that can be seen from a network of interconnected links. (see Figure 7).

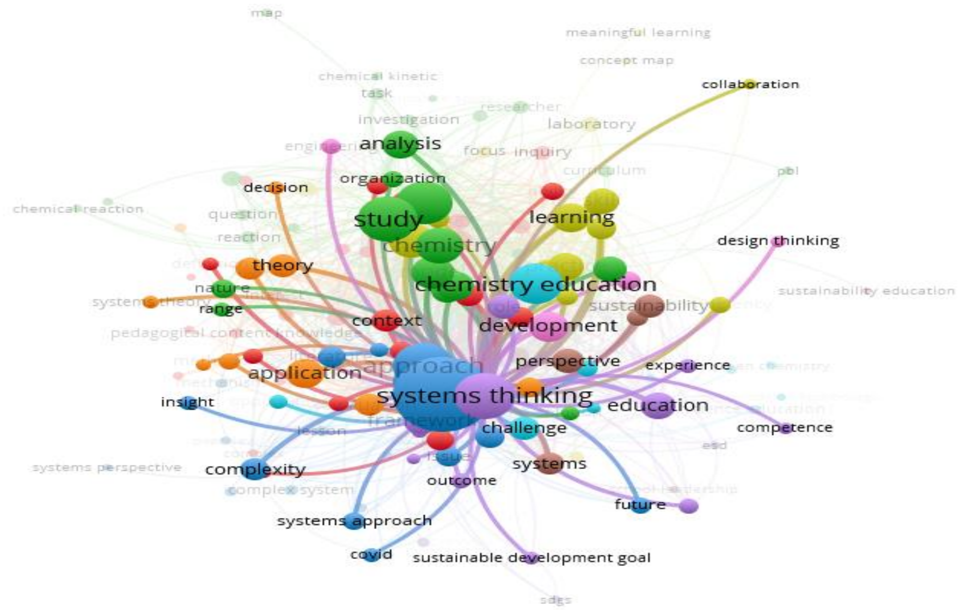

Figure 7. Networking System Thinking.

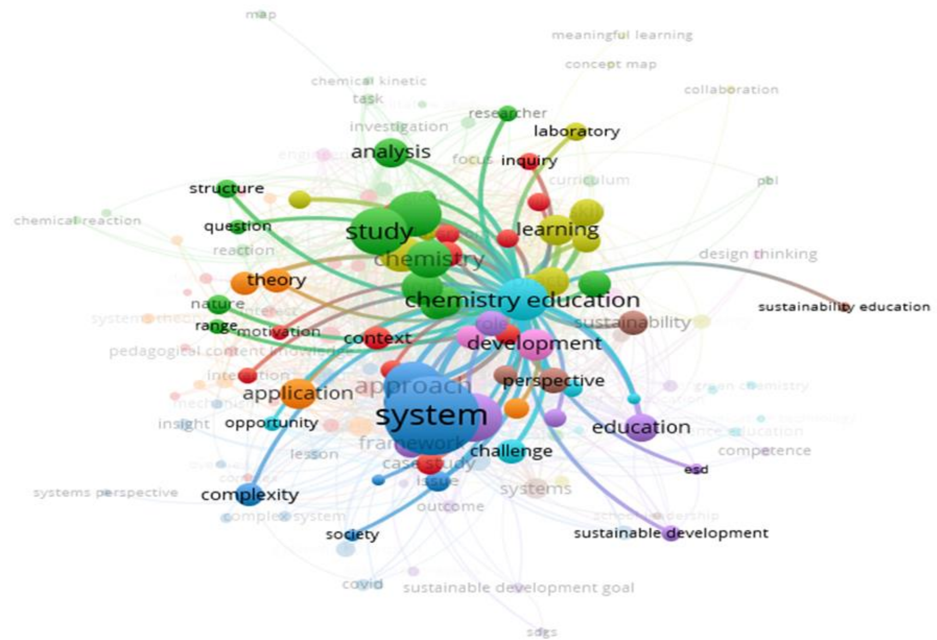

Figure 8. Networking Chemistry Education.

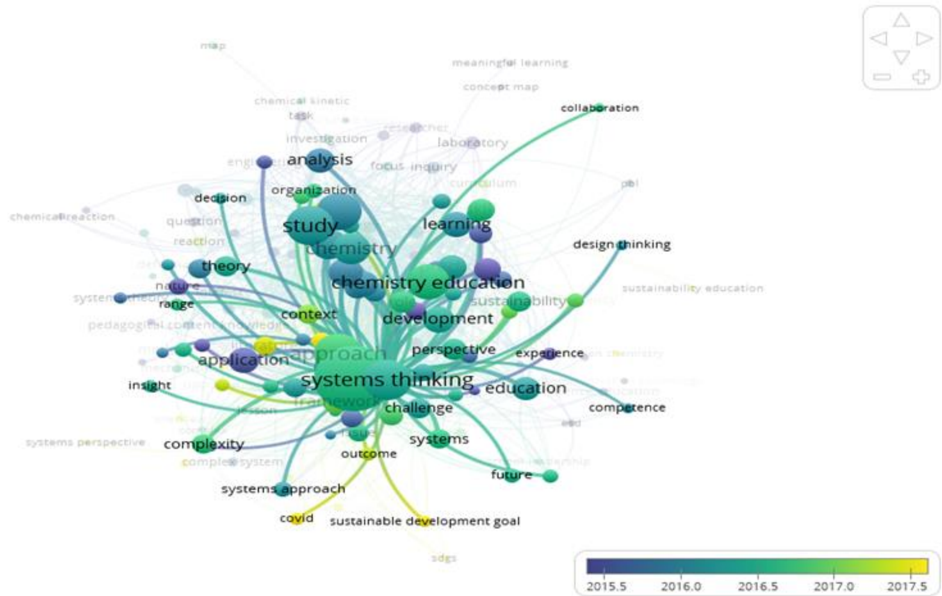

Figure 9. Overlay Visualization of Systems Thinking in Chemistry Education Term

Figure 5 shows the density visualization. Density visualization means that the brighter the yellow color and the larger the circle diameter of the term label, the more frequently the term appears. This means that much research on related terms has been done. Otherwise, if the color of the term fades closer to the background color, then the amount of research on the term is small. Based on Figure 4, it can be seen that research related to the term systems thinking has a circle diameter label that is not large, and the color of the term fades, so research studies on systems thinking are low. Meanwhile, in terms of chemistry education research, the diameter of the label circle is quite large, and the greenish-yellow color indicates that chemistry education research is quite high. Meanwhile, the term systems thinking in chemistry education has yet to appear, which means that studies related to systems thinking in education are still rare.

Figure 9 shows an overlay visualization of systems thinking research in chemistry education. This visualization overlay shows the novelty of research on related terms. Figure 5, clarified in Figure 9, shows that most of the research on systems thinking in chemistry education was conducted from the beginning of 2016 to 2017. The popularity of systems thinking and chemistry education in research has been around for a long time. Because of that, we can easily make new research on systems thinking in chemistry education.

From the results of this mapping, system thinking in chemistry education is still very minimal to learn—especially the application of systems thinking in chemistry education in Indonesia. So far, chemistry education in Indonesia only emphasizes the analysis and synthesis of chemical reaction processes. Not all students are trained to study chemistry for human, social, and environmental welfare. This makes students have weaknesses in understanding their chemistry learning outcomes. The challenge of future chemistry education is related to global sustainability, which should pay attention to an authentic interdisciplinary context to teach students about the complexity of global problems, including social, economic, and environmental components. Therefore, more efforts are needed to introduce the concept of sustainability using systems thinking in chemistry education to address current and future problems. One of the efforts to introduce it to students is to incorporate aspects of systems thinking into the chemistry curriculum so that knowledge of chemical content, chemical context, peculiarities, and methodological characteristics of chemistry can answer educational challenges for sustainable development.

From the results of the bibliometric mapping, it can be seen that previous researchers who focused on researching systems thinking in chemistry education were York, Orgill, and Mahaffy. They contributed to a literature review on systems thinking in chemistry education. Table 1 shows that Orgill, York, and Mahaffy are in the top 20 publications on systems thinking in chemistry education. In the top 20 publications, York, Orgill, and Mahaffy have the same number of publications of 4 articles. However, Mahaffy has the highest number of citations, with 350 citations, while York and Orgill have 321. Globally, Mahaffy is currently very popular among researchers in chemistry with an interest in systems thinking because it has many citations and the most frequent research related to systems thinking in chemistry education. Mahaffy's research emphasizes chemistry learning that is oriented towards the basic principles of sustainable molecules by integrating systems thinking. Mahaffy's application of this concept is evident within general chemistry. In addition, the exploration of systems thinking in chemistry education extends to Indonesia. Notably, Sidiq et al. have embarked on research investigating systems thinking for sustainable chemistry education. Their study aligns harmoniously with the researcher's bibliometric analysis findings, underscoring systems thinking as a pivotal bridge connecting the fundamental tenets of molecular chemistry with sustainability principles to address impending challenges. Notably, Sidiq et al.'s research findings expound upon the substantial role of systems thinking in cultivating students' problem-solving abilities and fostering sustainable development perspectives. Through the lens of systems thinking, students are challenged to grasp scientific processes holistically, transcending individual components to comprehend their interconnectedness and broader implications [45]. Besides that, Sidiq et al. researched Contemporary Hybrid Laboratory Pedagogy by constructing a Simple Spectrophotometer with STEM Project-Based Learning to Introduce Systems Thinking Skills [46].

The outcomes of this analysis unveil a promising potential for addressing the complex task of advancing sustainable chemistry education in Indonesia. Applying systems thinking research extends its reach to more advanced fields like inorganic chemistry, coordination chemistry, and organic chemistry. Nonetheless, it's noteworthy that the exploration of systems thinking remains concentrated within general chemistry education. Moreover, an expansive opportunity awaits further exploration, particularly in reinforcing systems thinking, by integrating laboratory-based activities and STEM project-based learning models. This integration is key to tackling challenges, propelling problem-solving capacities, and nurturing sustainable chemistry education.

The emergence of systems thinking research within the realm of chemistry education in Indonesia marks an important stride. This nascent exploration carries the potential to illuminate pathways for refinement, development, and potential avenues for expansion. In particular, it can shed light on the research gaps yet to be addressed, thereby contributing significantly to the evolution and enhancement of sustainable chemistry education. The ongoing research endeavors centered on systems thinking within the Indonesian context promise to furnish invaluable insights and innovative ideas that will continue to shape and redefine the landscape of sustainable chemistry education.

CONCLUSION

This research aims to analyze the bibliometric data mapping of research articles. The publication theme taken in this research is "Systems Thinking in Chemistry Education." The articles are taken from the Google Scholar database via Publish or Perish. The library data used in this study includes titles and abstracts. From the search results, 926 relevant articles were published from 2013 to 2022. The results showed that research on systems thinking and chemistry education had decreased from 2019 to 2022. The results showed that the opportunities for research on systems thinking in chemistry education still have great opportunities. It's quite high and related to other terms. Conclusions are written clearly and succinctly.

ACKNOWLEDGMENT

We thank the Ministry of Education and Culture, the Republic of Indonesia, for financial support through the LPDP scholarship.

REFERENCES

[1] B. Kisworo, A. Mudzakir, and S. Liliasari, “How does the chemistry of rare earth metals coordination complexes enhance system thinking ability ? A qualitative content analysis study,” vol. 2, pp. 301–311, 2021, doi:10.48317/IMIST.PRSM/morjchem-v9i2.27582.

[2] O. Ben-Zvi-Assaraf and N. Orion, “Four case studies, six years later: Developing system thinking skills in junior high school and sustaining them over time,” *J. Res. Sci. Teach.*, vol. 47, no. 10, pp. 1253–1280, 2010, doi: 10.1002/tea.20383.

[3] O. B. Z. Assaraf and N. Orion, “Development of system thinking skills in the context of earth system education,” *J. Res. Sci. Teach.*, vol. 42, no. 5, pp. 518–560, 2005, doi: 10.1002/tea.20061.

[4] J. C. Hong, M. Y. Chen, and M. Y. Hwang, “Vitalizing creative learning in science and technology through an extracurricular club: A perspective based on activity theory,” *Think. Ski. Creat.*, vol. 8, no. 1, pp. 45–55, 2013, doi: 10.1016/j.tsc.2012.06.001.

[5] G. Carey, E. Malbon, N. Carey, A. Joyce, B. Crammond, and A. Carey, "Systems science and systems thinking for public health: A systematic review of the field," *BMJ Open*, vol. 5, no. 12, pp. 1–9, 2015, doi: 10.1136/bmjopen-2015-009002.

[6] T. N. Hrin, D. D. Milenković, M. D. Segedinac, and S. Horvat, "Enhancement and assessment of students' systems thinking skills by application of systemic synthesis questions in the organic chemistry course," *J. Serbian Chem. Soc.*, vol. 81, no. 12, pp. 1455–1471, 2016, doi: 10.2298/JSC160811097H.

[7] P. G. Mahaffy, S. A. Matlin, J. M. Whalen, and T. A. Holme, "Integrating the Molecular Basis of Sustainability into General Chemistry through Systems Thinking," *J. Chem. Educ.*, vol. 96, no. 12, pp. 2730–2741, 2019, doi: 10.1021/acs.jchemed.9b00390.

[8] R. Lavi and Y. J. Dori, "Systems thinking of pre- and in-service science and engineering teachers," *Int. J. Sci. Educ.*, vol. 41, no. 2, pp. 248–279, 2019, doi:10.1080/09500693.2018.1548788.

[9] X. Wang, Z. Xu, and M. Škare, "A bibliometric analysis of Economic Research-Ekonomska Istraživanja (2007–2019)," *Econ. Res. Istraz.* , vol. 33, no. 1, pp. 865–886, 2020, doi: 10.1080/1331677X.2020.1737558.

[10] M. Castillo-Vergara, A. Alvarez-Marin, and D. Placencio-Hidalgo, "A bibliometric analysis of creativity in business economics," *J. Bus. Res.*, vol. 85, no. March 2017, pp. 1–9, 2018, doi: 10.1016/j.jbusres.2017.12.011.

[11] N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, and W. M. Lim, "How to conduct a bibliometric analysis: An overview and guidelines," *J. Bus. Res.*, vol. 133, no. March, pp. 285–296, 2021, doi: 10.1016/j.jbusres.2021.04.070.

[12] E. Djeki, J. Dégila, C. Bondiombouy, and M. H. Alhassan, "E-learning bibliometric analysis from 2015 to 2020," *J. Comput. Educ.*, vol. 9, no. 4, pp. 727–754, 2022, doi: 10.1007/s40692-021-00218-4.

[13] F. G. A. De Bakker, P. Groenewegen, and F. Den Hond, "A bibliometric analysis of 30 years of research and theory on corporate social responsibility and corporate social performance," *Bus. Soc.*, vol. 44, no. 3, pp. 283–317, 2005, doi: 10.1177/0007650305278086.

[14] N. M. Modak, V. Lobos, J. M. Merigó, B. Gabrys, and J. H. Lee, "Forty years of computers & chemical engineering: A bibliometric analysis," *Comput. Chem. Eng.*, vol. 141, 2020, doi:10.1016/j.compchemeng.2020.106978.

[15] P. Grandjean, M. L. Eriksen, O. Ellegaard, and J. A. Wallin, "The Matthew effect in environmental science publication: A bibliometric analysis of chemical substances in journal articles," *Environ. Heal. A Glob. Access Sci. Source*, vol. 10, no. 1, pp. 1–8, 2011, doi: 10.1186/1476-069X-10-96.

[16] B. Kisworo, A. Mudzakir, S. Liliasari, A. Permanasari, and N. Novia, "Twenty Years of Research Development on Systems Thinking in Rare Earth Coordination Chemistry : A Bibliometric Analysis," *J. Eng. Sci. Technol.*, vol. 18, no. 3, pp. 137–144, 2023.

[17] A. S. Shidiq, A. Permanasari, Hernani, and S. Hendayana, "The use of simple spectrophotometer in STEM education: A bibliometric analysis," *Moroccan J. Chem.*, vol. 9, no. 2, pp. 290–300, 2021, doi: 10.48317/IMIST.PRSM/morjchem-v9i2.27581.

[18] Y. S. Ho, "Top-cited articles in chemical engineering in science citation index

expanded: A bibliometric analysis," *Chinese J. Chem. Eng.*, vol. 20, no. 3, pp. 478–488, 2012, doi: 10.1016/S1004-9541(11)60209-7.

[19] A. B. D. Nandiyanto, D. N. Al Husaeni, and D. F. Al Husaeni, "A bibliometric analysis of chemical engineering research using vosviewer and its correlation with Covid-19 pandemic condition," *J. Eng. Sci. Technol.*, vol. 16, no. 6, pp. 4414–4422, 2021.

[20] D. N. Al Husaeni, A. B. D. Nandiyanto, and R. Maryanti, "Bibliometric Analysis of Special Needs Education Keyword Using VOSviewer Indexed by Google Scholar," *Indones. J. Community Spec. Needs Educ.*, vol. 3, no. 1, pp. 1–10, 2022, doi: 10.17509/ijcsne.v3i1.43181.

[21] D. F. Al Husaeni, A. B. D. Nandiyanto, and R. Maryanti, "Bibliometric analysis of educational research in 2017 to 2021 using VOSviewer: Google scholar indexed research," *Indones. J. Teach. Sci.*, vol. 3, no. 1, pp. 1–8, 2023, doi: 10.17509/ijotis.v3i1.43182.

[22] N. U. I. Hossain, V. L. Dayarathna, M. Nagahi, and R. Jaradat, "Systems thinking: A review and bibliometric analysis," *Systems*, vol. 8, no. 3, pp. 1–26, 2020, doi: 10.3390/systems8030023.

[23] D. F. Al Husaeni and A. B. D. Nandiyanto, "Bibliometric Computational Mapping Analysis of Publications on Mechanical Engineering Education Using Vosviewer," *J. Eng. Sci. Technol.*, vol. 17, no. 2, pp. 1135–1149, 2022.

[24] S. A. Matlin, G. Mehta, H. Hopf, and A. Krief, "One-world chemistry and systems thinking," *Nat. Chem.*, vol. 8, no. 5, pp. 393–398, 2016, doi: 10.1038/nchem.2498.

[25] M. K. Orgill, S. York, and J. Mackellar, "Introduction to Systems Thinking for the Chemistry Education Community," *J. Chem. Educ.*, vol. 96, no. 12, pp. 2720–2729, 2019, doi: 10.1021/acs.jchemed.9b00169.

[26] P. G. Mahaffy, A. Krief, H. Hopf, G. Mehta, and S. A. Matlin, "Reorienting chemistry education through systems thinking," *Nat. Rev. Chem.*, vol. 2, no. 4, pp. 1–3, 2018, doi: 10.1038/S41570-018-0126.

[27] E. Saxton *et al.*, "A Common Measurement System for K-12 STEM education: Adopting an educational evaluation methodology that elevates theoretical foundations and systems thinking," *Stud. Educ. Eval.*, vol. 40, pp. 18–35, 2014, doi: 10.1016/j.stueduc.2013.11.005.

[28] K. M. Jegstad and A. T. Sinnes, "Chemistry Teaching for the Future: A model for secondary chemistry education for sustainable development," *Int. J. Sci. Educ.*, vol. 37, no. 4, pp. 655–683, 2015, doi: 10.1080/09500693.2014.1003988.

[29] S. York, R. Lavi, Y. J. Dori, and M. K. Orgill, "Applications of Systems Thinking in STEM Education," *J. Chem. Educ.*, vol. 96, no. 12, pp. 2742–2751, 2019, doi: 10.1021/acs.jchemed.9b00261.

[30] P. G. Mahaffy, S. A. Matlin, T. A. Holme, and J. MacKellar, "Systems thinking for education about the molecular basis of sustainability," *Nat. Sustain.*, vol. 2, no. 5, pp. 362–370, 2019, doi: 10.1038/s41893-019-0285-3.

[31] S. Nagarajan and T. Overton, "Promoting Systems Thinking Using Project- And Problem-Based Learning," *J. Chem. Educ.*, vol. 96, pp. 2901–2909, 2019, doi: 10.1021/acs.jchemed.9b00358.

[32] M. Reynolds, C. Blackmore, R. Ison, R. Shah, and E. Wedlock, "The Role of Systems Thinking in Implementing Sustainable Development Goals," *World Sustain. Ser.*, pp. 677–698, 2018, doi: 10.1007/978-3-319-63007-6_42.

[33] K. B. Aubrecht, M. Bourgeois, E. J. Brush, J. Mackellar, and J. E. Wissinger, "Integrating Green Chemistry in the Curriculum: Building Student Skills in Systems Thinking, Safety, and Sustainability," *J. Chem. Educ.*, vol. 96, no. 12, pp. 2872–2880, 2019, doi: 10.1021/acs.jchemed.9b00354.

[34] T. Vachliotis, K. Salta, and C. Tzougraki, "Meaningful Understanding and Systems Thinking in Organic Chemistry: Validating Measurement and Exploring Relationships," *Res. Sci. Educ.*, vol. 44, no. 2, pp. 239–266, 2014, doi: 10.1007/s11165-013-9382-x.

[35] P. G. Mahaffy, E. J. Brush, J. A. Haack, and F. M. Ho, "Journal of Chemical Education Call for Papers - Special Issue on Reimagining Chemistry Education: Systems Thinking, and Green and Sustainable Chemistry," *J. Chem. Educ.*, vol. 95, no. 10, pp. 1689–1691, 2018, doi: 10.1021/acs.jchemed.8b00764.

[36] T. D. Lee, M. Gail Jones, and K. Chesnutt, "Teaching Systems Thinking in the Context of the Water Cycle," *Res. Sci. Educ.*, vol. 49, no. 1, pp. 137–172, 2019, doi: 10.1007/s11165-017-9613-7.

[37] G. A. Hurst, "Systems thinking approaches for international green chemistry education," *Curr. Opin. Green Sustain. Chem.*, vol. 21, pp. 93–97, 2020, doi: 10.1016/j.cogsc.2020.02.004.

[38] S. Pazicni and A. B. Flynn, "Systems Thinking in Chemistry Education: Theoretical Challenges and Opportunities," *J. Chem. Educ.*, vol. 96, no. 12, pp. 2752–2763, 2019, doi: 10.1021/acs.jchemed.9b00416.

[39] D. J. C. Constable, C. Jiménez-González, and S. A. Matlin, "Navigating Complexity Using Systems Thinking in Chemistry, with Implications for Chemistry Education," *J. Chem. Educ.*, vol. 96, no. 12, pp. 2689–2699, 2019, doi: 10.1021/acs.jchemed.9b00368.

[40] A. B. Flynn *et al.*, "Future Directions for Systems Thinking in Chemistry Education: Putting the Pieces Together," *J. Chem. Educ.*, vol. 96, no. 12, pp. 3000–3005, 2019, doi: 10.1021/acs.jchemed.9b00637.

[41] V. Talanquer, "Some Insights into Assessing Chemical Systems Thinking," *J. Chem. Educ.*, vol. 96, no. 12, pp. 2918–2925, 2019, doi: 10.1021/acs.jchemed.9b00218.

[42] S. York and M. K. Orgill, "ChEMIST Table: A Tool for Designing or Modifying Instruction for a Systems Thinking Approach in Chemistry Education," *J. Chem. Educ.*, vol. 97, no. 8, pp. 2114–2129, 2020, doi: 10.1021/acs.jchemed.0c00382.

[43] W. Li *et al.*, "Progression of mental health services during the COVID-19 outbreak in China," *Int. J. Biol. Sci.*, vol. 16, no. 10, pp. 1732–1738, 2020, doi: 10.7150/ijbs.45120.

[44] A. B. D. Nandiyanto and D. F. Al Husaeni, "A bibliometric analysis of materials research in Indonesian journal using VOSviewer," *J. Eng. Res.*, vol. 9, pp. 1–16, 2021, doi: 10.36909/jer.ASSEEE.16037.

[45] A. S. Shidiq, A. Permanasari, and Hernani, "Review on education for sustainable development: System thinking for sustainable chemistry education curriculum," *J. Phys. Conf. Ser.*, vol. 1521, no. 4, 2020, doi: 10.1088/1742-6596/1521/4/042080.

[46] A. S. Shidiq, A. Permanasari, Hernani, and S. Hendayana, " Contemporary Hybrid Laboratory Pedagogy: Construction of A Simple Spectrophotometer with STEM Project-Based Learning to Introduce Systems Thinking Skills," A*sia Pacific Journal of Educators and Education*, vol. 37, no.2, pp. 107-146, 2022.