Journal of Engineering Science and Technology
Special Issue on ISCoE2022 Vol. 18, No. 3 (2023) 137 - 144

TWENTY YEARS OF RESEARCH DEVELOPMENT ON SYSTEMS THINKING IN RARE EARTH COORDINATION CHEMISTRY: A BIBLIOMETRIC ANALYSIS

BANU KISWORO[1,2], AHMAD MUDZAKIR[1,*],
L. LILIASARI[1], ANNA PERMANASARI[3], N. NOVIA[1,3]

[1]Universitas Pendidikan Indonesia, Jl. Dr. Setiabudhi no 299, Bandung, 40154, Indonesia
[2]Universitas Muhammadiyah Cirebon, Jl. Tuparev no 70, Cirebon, 45153, Indonesia
[3]Universitas Pakuan Bogor, Jl. Tegalega, Bogor tengah, Bogor, 16144, Indonesia
*Corresponding Author: mudzakir.kimia@upi.edu

Abstract

The purpose of this bibliometric analysis is to assess trends and the impact of publications published within the last 20 years on the topic of systems thinking in rare earth coordination chemistry, from 2002 to 2022. This analysis is based on the Scopus database and reviewed using VOS viewers. This study uses 216 documents which are then sorted into 215 relevant articles. Based on the results of the analysis, the United States of America was identified as the most productive country in researching systems thinking and rare earths in coordination complexes (38.60%). The most published documents are in the form of books (41.4%), while only a few are published in the form of articles (27.4%). Chen X is a writer who is dominant in publishing about rare earth coordination complexes or systems thinking in book form. Meanwhile, the bibliometric analysis shows that the trend from year to year in research on rare earth coordination complexes is still detached from the aspects of systems thinking. This opens up opportunities to conduct rare earth coordination chemistry research by integrating systems thinking skills.

Keywords : Bibliometric analysis; Coordination chemistry; E-waste; Rare earth; Systems thinking.

1. Introduction

Systems thinking in rare earth coordination chemistry is an appropriate alternative method for students to solve the problem of electronic waste in the environment. In several studies that have been conducted, electronic waste has become a global problem and requires solutions in the field of chemistry as well as being a learning environment for students [1-4]. As a result, environmental awareness through the waste recycling process must be included in relevant chemistry learning as an action in dealing with the problem of electronic waste that pollutes the environment. Electronic waste (e-waste) has been identified as containing rare earth metals.

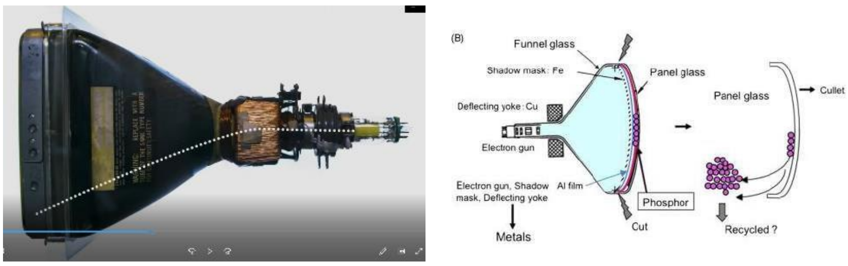
Many reports have discussed systems thinking in chemistry learning. Applying system thinking skills students can integrate molecular principles based on sustainability from economic, social, and environmental aspects [5]. Systems thinking has a very important role in teaching chemistry in the context of a catalyst. This research was conducted to describe the interrelationships of systems thinking bringing the concept that homogeneous and heterogeneous catalysts can be synthesized and to understand how the catalyst processes can work during chemical reaction processes and affect environmental and economic aspects [6]. Student systems thinking skills can be optimized by integrating chemical reaction principles through the DOZN 2.0 software inspired by the 12 principles of green chemistry and life cycle assessment (LCA) metrics [7]. There is a relationship between systems thinking and green chemistry in the context of green chemistry education. This study reviews existing research mapping, through a thematic synthesis process, and investigates the role of systems thinking in supporting green chemistry education [8]. Other research also discusses systems thinking frameworks that can be integrated into chemistry learning [9]. However, based on the above literature, no research focuses on systems thinking in rare earth coordination chemistry. In the study of coordination chemistry, the current potential research is the formation of coordination compounds of rare earth metals. This is because rare earth metals are strategic metals that can be applied to technological advances.

Based on previous research, no research has addressed the concept of synthesizing rare earth coordination complex compounds from recycled electronic waste, including the use of green chemistry chemical extractants that are environmentally friendly. Although the problem of e-waste is interesting to find appropriate techniques to reduce human environmental pollution. So this study analyzes the extent to which research related to the synthesis of rare earth coordination complex compounds from electronic waste has been carried out by previous researchers. Of course, this analysis requires the help of software to help map relevant research from the last few years. Although bibliometric studies in systems thinking and all related fields have been published previously, the concept of future studies related to rare earth coordination chemistry is not found in the scientific literature, this is a significant difference as well as a novelty from the current article. The second novelty of this study is the implementation of systems thinking related to the chemical content of rare earth elements. The third novelty of the study is integrating e-waste recycling technology with the principle of sustainability through systems thinking.

2. Literature Review

Systems thinking has been noticed by chemistry educators in recent years [1, 2]. Current research trends refer to the United Nations' SDGs program to encourage all disciplines to be oriented towards the principles of sustainability. Systems thinking has been used as a framework for integrating sustainable concepts as has been done [4]. Applying systems thinking in chemistry can be done through one approach, one of which is the Molecular basis of sustainability. The molecular basis of sustainability is a term that emphasizes that many environmental problems originate from the molecular dimension and the solutions offered also need to consider the molecular dimension [10]. The molecular basis of sustainability is ways in which social and economic aspects underlie considerations of how present and future generations can survive within the limitations of nature [4].

The principle of sustainability is particularly relevant in coordination chemistry, particularly on the topic of rare earth coordination complex compounds. These compounds have important applications in modern technological developments such as mobile phones, catalysts, magnets, electronics, and the defence industry. Rare earth coordination complexes are formed by coordinating bonds between the lanthanides and the ligands as electron donors. Systems thinking is needed in applying the principles of sustainability in synthesizing these complex compounds. One way that can be done is to utilize electronic waste that contains rare earth metals. Based on previous research, the waste in fluorescent lamps contains phosphorus powder which contains rare earth metals in the form of yttrium and europium [11]. This rare earth metal has the property of glowing light or can be called luminescent. Another example of electronic waste containing quite a lot of rare earth metals is found in tube TVs with Cathode Ray Tube (CRT) technology, as shown in Fig. 1(a). The CRT tube has the form of phosphor powder attached to a glass panel which is identical to fluorescent lamp waste because of its luminescent properties as shown in Fig. 1(b).



(a) **(b)**

Fig. 1. (a) TV cathode ray tube (b) CRT recycling scheme [5].

The e-waste recycling process is useful for collecting rare earth metals. This process must pay attention to environmentally friendly aspects and green chemistry. So that the selection of environmentally friendly solvents needs to be considered in this recycling process. The currently developed deep eutectic solvent (DES) is an ionic liquid that has environmentally friendly properties and serves as an alternative to a sustainable solvent. DES is a mixture of hydrogen bond donors and acceptors with a low melting point around ambient temperature. DES has characteristics such as low volatility, biodegradable, recyclable, and low cost of synthesis. DES is a useful solvent for recovering metals from industrial process residues and metal ores. The reaction processes involved in the extraction of rare earth metals are complex reactions. Complex reactions can take place because of the equilibrium reaction between the rare earth metals and the carboxylic groups present in the extractants. The result of this reaction is a rare earth coordination complex as shown in Fig. 2 [12]. The process of e-waste recycling technology [11].

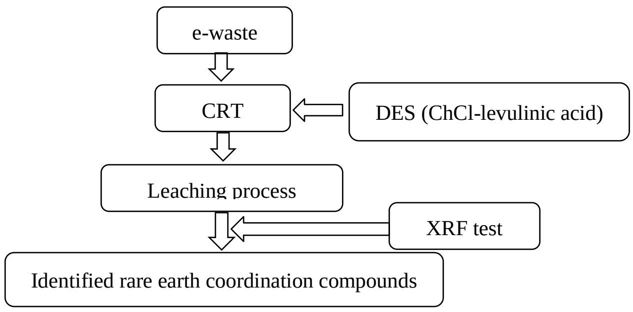


Fig 2. Technology recycling e-waste into rare earth coordination compound.

This study will contribute to the knowledge of systems thinking in the study of rare earth coordination complex chemistry against current problems and future trends that might affect systems thinking in rare earth coordination complex compounds. The study fills a gap in research spanning two decades, during which the research trend during this period was mostly in the fields of systems thinking and rare earth metals. Based on a bibliometric approach, this research complements publications related to systems thinking in the matter of rare earth coordination complex compounds.

3.Methods

In this study, a literature review was carried out in a structured manner by determining relevant keywords, searching for literature, and conducting an analysis as shown in Fig. 3 [13]. The collected literature was analysed using bibliometric analysis techniques. The software used is VOSviewer. The data is collected from the Scopus database because it has a wide scope, and the form of metadata is in the form of CSV. Search using the keyword "System thinking in science learning", with a time range from 2002 to 2022. Detailed information for the use of VOSviewer is reported elsewhere [14], and examples of the applications of VOSviewer are available in literature [15-17].

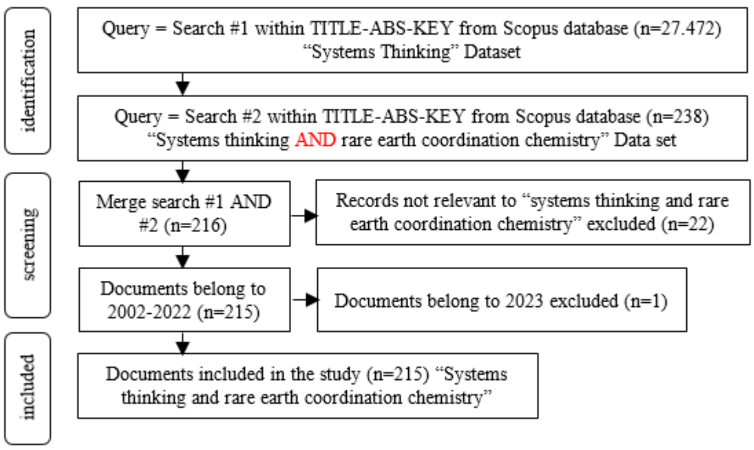


Fig. 3. Search strategy flow diagram.

4. Results and Discussion

The results of searching through the Scopus database were then sorted by 215 documents. The trend of research on systems thinking on the topic of chemistry learning from 2002 to 2022 based on documents published annually on the Scopus dataset is shown in Table 1. The research trend of using systems thinking in chemistry learning continues to increase and reaches a peak of publication in 2020 until 2022 with a total of 78 documents. Meanwhile, from 2002 to 2004, no one had conducted research on systems thinking in chemistry learning, so during this year, no researchers published this field. Table 1 shows the beginning of this research began in 2005.

Table 1. Documents every three years.

Year	Documents	Percentage (%)
2002 – 2004	0	0
2005 – 2007	4	1.86
2008 – 2010	16	7.44
2011 – 2013	34	15.81
2014 – 2016	32	14.88
2017 – 2019	51	23.72
2020 – 2022	78	36.27

Based on the type of documents obtained, it can be seen based on direct analysis from the Scopus website that most of the types of publications are books totalling 89 documents (41.2%). Apart from that, there were 60 documents (27.8%) and a review of 51 documents (23.6%) which contributed quite a lot to articles. Contributions of other types of documents that were smaller were book chapters totalling 13 documents (6%), conference papers totalling 2 documents (0.9%), and short surveys (0.5%).

To find out the conceptual structure of systems thinking research on the topic of rare earth coordination chemistry, co-word analysis can be carried out which is mapped and grouped into co-occurrence (Fig. 4). Each node shows one keyword. The larger node size indicates the greater the frequency of the keyword. Each node is connected by a link [18-20]. The largest node in this study is metal complex, this indicates that metal complex compounds are the most popular keywords. In addition, another big node, namely rare earth, is another popular keyword after metal complex compounds. The nodes that show systematic thinking also have a fairly large size. Figure 4 also shows that the nodes on rare earth with systematic thinking are not directly connected. This indicates that studies on systems thinking on the topic of the coordination chemistry of rare earth have never been conducted before. Therefore, research on systems thinking in the coordination chemistry of rare earth can be studied more deeply for further research.

Based on the results of the overlay visualization on the VOS viewer, it describes various keywords indicating the latest research with light green to yellow indicators [21, 22]. Figure 5 shows that several terms that look new and are the latest research trends related to this study include complex metals, rare earth, alloys, strategic thinking, systematic thinking, and artificial intelligence. Thus, systems thinking on the topic of soil coordination chemistry rarely has a great opportunity to be researched because there has been no previous research from 2002 to 2022 based on Scopus data and the results of study analysis that have been obtained. The application of systems thinking in soil coordinating chemistry is rarely a research novelty because it has great potential to address global challenges in programs that have been proclaimed by the world, namely sustainable molecular principles and green chemistry principles based on electronic waste recycling technology. This study can be implemented for chemistry students and chemistry education students in increasing their understanding and systems thinking about coordinating chemistry concepts associated with environmental, scientific, technological, and social aspects. This is in line with research [10], that sustainable molecular principles need to be incorporated into student learning, especially in the field of chemistry education.

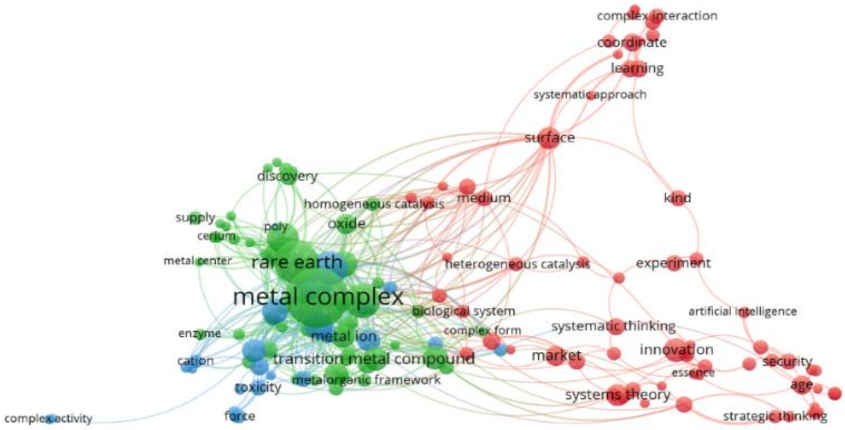


Fig. 4. Visualization of the conceptual structure of systems thinking research on the topic of rare earth coordination chemistry.

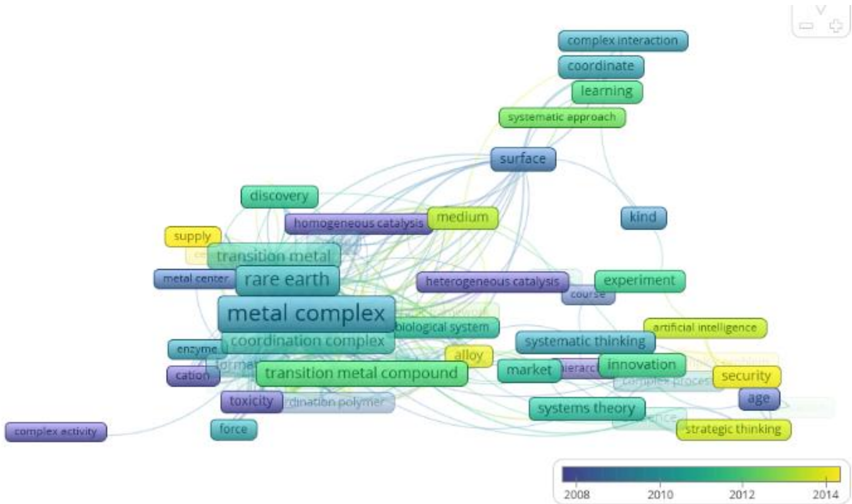


Fig. 5. Overlay visualization of the use of systems thinking in rare earth coordination chemistry (2002 – 2022).

Based on the results of the bibliometric analysis above, 4 keywords appear most often. This indicates that many previous studies have been carried out relating to metal complexes, rare earths, coordination complexes and systems thinking.

However, when viewed from the connection network in Fig. 5, only three keywords are connected, namely metal complex, rare earth, and coordination complex. This indicates that so far the research that has been carried out has only linked metal complexes, rare earth, and coordination complexes, but nothing has linked them with systems thinking. The four identified keyword trends bring research potential that discusses systems thinking in the coordination chemistry of rare earth metals. Other research potentials for the future are also related to global issues regarding green chemistry and sustainability aspects. Thus, if research on system thinking in the coordination chemistry of rare earth is carried out starting from the context of electronic waste and based on the principle of green chemistry, it will provide stronger opportunities for future research.

5. Conclusions

This study conducted bibliometric analysis by reviewing 215 selected documents based on the use of systems thinking in rare earth coordination chemistry by utilizing the VOS viewer software application. The results of this study reveal that several topics have become the latest research trends and are related to this study including complex metals, rare earth, alloys, strategic thinking, systematic thinking, and artificial intelligence. The bibliometric study carried out can provide complete information about systems thinking research in rare earth coordination chemistry, especially those that are meaningful for researchers for future research development.

Acknowledgments

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

References

1. Hrin, T.N.; Milenković, D.D.; Segedinac, M.D.; and Horvat, S. (2017). Systems thinking in chemistry classroom: The influence of systemic synthesis questions on its development and assessment. *Thinking Skills and Creativity*, 23, 175-187.
2. Kisworo, B.; Mudzakir, A.; and Liliasari, S. (2021). How does chemistry of rare earth metals coordination complexes can enhance system thinking ability?A qualitative content analysis study. *Moroccan Journal of Chemistry*, 9(2),301-311.
3. Kisworo, B.; Liliasari, S.; and Mudzakir, A. (2021). The analysis of content teaching materials: Identification of potential for developing systems thinking skills in coordination chemistry. *Journal of Physics: Conference Series* 1806(1), 012208.
4. Mahaffy, P.G.; Matlin, S.A.; Holme, T.A.; and MacKellar, J. (2019). Systems thinking for education about the molecular basis of sustainability. *Nature Sustainability*, 2(5), 362-370.
5. Pinasti, T.; Mudzakir, A.; and Hernani. (2022). Can the chemistry of rare earth elements enhance student's system thinking? A qualitative content analysis. *AIP Conference Proceedings*, 2468 (1), 040005.
6. Ravi, M.; Puente-Urbina, A.; and van Bokhoven, J.A. (2021). Identifying opportunities to promote systems thinking in catalysis education. *Journal of Chemical Education*, 98(5), 1583-1593.
7. Reyes, K.M.; Bruce, K.; and Shetranjiwalla, S. (2022). Green chemistry, life cycle assessment, and systems thinking: An integrated comparative-

complementary chemical decision-making approach. *Journal of Chemical Education*, 100(1), 209-220.
8. Paschalidou, K.; Salta, K.; and Koulougliotis, D. (2022). Exploring the connections between systems thinking and green chemistry in the context of chemistry education: A scoping review. *Sustainable Chemistry and Pharmacy*, 29, 100788.
9. Flynn, A.B.; Orgill, M.; Ho, F.M.; York, S.; Matlin, S.A.; Constable, D.J.; and Mahaffy, P.G. (2019). Future directions for systems thinking in chemistry education: Putting the pieces together. *Journal of Chemical Education*, 96(12), 3000-3005.
10. Anastas, P.T.; and Zimmerman, J.B. (2016). The molecular basis of sustainability. *Chem*, 1(1), 10-12.
11. Pateli, I.M.; Abbott, A.P.; Binnemans, K.; and Rodriguez, N.R. (2020). Recovery of yttrium and europium from spent fluorescent lamps using pure levulinic acid and the deep eutectic solvent levulinic acid–choline chloride. *RSC Advances*, 10(48), 28879-28890.
12. Bünzli, J.C.G. (2014). Lanthanide coordination chemistry: From old concepts to coordination polymers. *Journal of Coordination Chemistry*, 67(23-24), 3706-3733.
13. Rowley, J.; and Slack, F. (2004). Conducting a literature review. *Management Research News*, 27(6), 31-39.
14. Al Husaeni, D.F.; and Nandiyanto, A.B.D. (2022). Bibliometric using VOSviewer with publish or perish (using google scholar data): From step-by-step processing for users to the practical examples in the analysis of digital learning articles in pre and post covid-19 pandemic. *ASEAN Journal of Science and Engineering*, 2(1), 19-46.
15. Soegoto, H.; Soegoto, E.S.; Luckyardi, S.; and Rafdhi, A.A. (2022). A bibliometric analysis of management bioenergy research using vosviewer application. *Indonesian Journal of Science and Technology*, 7(1), 89-104.
16. Setiyo, M.; Yuvenda, D.; and Samue, O.D. (2021). The concise latest report on the advantages and disadvantages of pure biodiesel (B100) on engine performance: Literature review and bibliometric analysis. *Indonesian Journal of Science and Technology*, 6(3), 469-490.
17. Utama, D.M.; Santoso, I.; Hendrawan, Y.; and Dania, W.A.P. (2023). Sustainable production-inventory model with multi-material, quality degradation, and probabilistic demand: From bibliometric analysis to a robust model. *Indonesian Journal of Science and Technology*, 8(2), 171-196.
18. Liu, Z.; Yin, Y.; Liu, W.; and Dunford, M. (2015). Visualizing the intellectual structure and evolution of innovation systems research: A bibliometric analysis. *Scientometrics*, 103, 135-158.
19. Wang, M.; and Chai, L. (2018). Three new bibliometric indicators/approaches derived from keyword analysis. *Scientometrics*, 116, 721-750.
20. Novia, N.; Riandi, R.; Permanasari, A.; and Kaniawati, I. (2022). Hot topics and frontier evolution of game in stem learning research: A bibliometric mapping from 2002 to 2022. *Jurnal Inspirasi Pendidikan*, 12(2), 120-128.
21. Hossain, N.U.I.; Dayarathna, V.L.; Nagahi, M.; and Jaradat, R. (2020). Systems thinking: A review and bibliometric analysis. *Systems*, 8(3), 23.
22. Fauzi, M.A. (2022). E-learning in higher education institutions during COVID-19 pandemic: Current and future trends through bibliometric analysis. *Heliyon*, e09433.