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Technological Pedagogical Content Knowledge in Chemistry Education: A Review and Bibliometric Analysis Using VOSviewer and RStudio Applications

Marlina [1] *, Abdul Rahim [1], Reny Refitaningsih Peby Ria [2], Heri Sopian Hadi [1]**
[1]*Department of Information Technology Education, Faculty of Engineering, Bumigora University, Jl. Ismail Marzuki, Mataram 83127, Indonesia*
[2]*Department of Computer Scince, Faculty of Engineering, Bumigora University, Jl. Ismail Marzuki, Mataram 83127, Indonesia*
**Corresponding author, Email address: marlina@universitasbumigora.ac.id*
***Corresponding author, Email address: abdul.rahim@universitasbumigora.ac.id*

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Abstract: Technological Pedagogical Content Knowledge (TPACK) has become very important as technology has become an integral part of chemistry learning. The purpose of this study is to present a bibliometric and bibliographic review of various high-quality literature on TPACK in chemistry education. The bibliometric analysis used VOSviewer and RStudio. There were 22 literatures from the Scopus database published from 2011-2022. The results showed that publications increased slightly from 2018-2020 and decreased in 2020-2023. In 2012, 2013, 2016, and 2018 no articles were published, while citations to articles increased in 2018-2022 and tended to fluctuate in 2011-2018. There are 5 clusters. Cluster 1 (44 items), cluster 2 (39 items), cluster 3 (28 items), cluster 4 (21 items), and cluster 5 (11 items). In addition, papers were published by mostly Indonesian researchers. This study provides information for education researchers related to TPACK in chemistry education in the implementation of chemistry learning does not seem to have been done much which is expected to strengthen the topic of future researchers.

Keywords: TPACK, Chemistry Education, Bibliometric

1. Introduction

The challenges of the development of an increasingly technology-oriented world require the availability of human resources who master science, technology and art (IPTEKS) (Aiym *et al.,* 2022; Yılmaz et al., 2021). The use of technology in learning in the 5.0 era is a determining factor in the effectiveness of learning (Baber, 2020; Marlina *et al.,* 2021; Sajidan *et al.,* 2022). A teacher is expected to combine technology in the learning process. This will spur various aspects, namely student engagement (Ramamuruthy & Rao, 2015) the attractiveness of the material (Rahim *et al.,* 2020), as well as ease in the process of delivering material (Gunawardhana, 2020). Technology integration in education has become a necessity in today's digital era. In the learning process, technology enables the use of various tools and applications that can enrich students' learning (Aguirre *et al.,* 2022; Lrhoul *et al.* 2023), such as interactive learning videos (Marlina & Riyanto, 2021), and online learning platforms.

Utilizing technology, students can learn in a more interesting and enjoyable way (Rahim et al., 2020). Interactive learning video (AFIFY, 2020) for example, can help students understand complex concepts more easily (Lapitan et al., 2021; Martín-Gutiérrez et al., 2017), due to engaging visualizations and interactions that can enhance understanding. Technology integration can also help educators prepare materials and evaluate students' learning progress (Redecker, 2017) With the online learning platform, teachers can create assignments and exams digitally, making it easier for them to provide feedback and control the student learning (Hadi et al., 2022; Plump & LaRosa, 2017). The ability to use and combine various dimensions of knowledge for effective learning with technology is often called TPACK (Technological Pedagogical Content Knowledge) (Schmid et al., 2020).

TPACK is a conceptual framework used to explain how teachers can effectively integrate technology in the teaching and learning process. TPACK incorporates three types of knowledge that teachers should have, namely content knowledge, pedagogical knowledge, and technological knowledge. The concept of TPACK was first coined by Mishra and Koehler (Mishra & Koehler, 2006). TPACK is the knowledge needed by teachers to integrate technology into specific learning materials into a complete package. In other words, TPACK is a combination of Technological Knowledge (TK), Pedagogical Knowledge (PK), Content Knowledge (CK), Technological Pedagogical Knowledge (TPK), Pedagogical Content Knowledge (PCK), and Technological Content Knowledge (TCK) (Mishra & Koehler, 2006). Based on the explanation above, the TPACK concept is in line with efforts to improve teachers' ability to master ICT. In the context of chemistry education, TPACK is very important because technology has become an integral part of chemistry learning (Carpendale et al., 2020; Widyasari et al., 2022; Zimmermann et al., 2021). In an increasingly digitally connected world, chemistry teachers must be able to integrate technology in their learning in order to provide a more interesting, interactive, and effective learning experience for students (Baber, 2020; Rahim et al., 2020; Sajidan et al., 2022). Therefore, the development of TPACK among chemistry teachers should be a priority to ensure that teachers have the knowledge and skills needed to integrate technology in their learning effectively (Bedin et al., 2023; Jannah et al., 2019; Khan, 2011). This will help students gain a better understanding of chemistry concepts and help them prepare for an increasingly digital future.

The topic of TPACK research has been widely discussed (Hsu & Chen, 2023; Kong et al., 2023; Sofyan et al., 2023; Sun et al., 2023; Zhou et al., 2023). TPACK topics in mathematics education matematika (Galanti et al., 2021; Mailizar et al., 2021; Rakes et al., 2022), TPACK in biology education (Juanda et al., 2021; Novidsa et al., 2021; Purwianingsih et al., 2022), TPACK in physics education fisika (Cengiz, 2015; Lee et al., 2021; Tanucan et al., 2021), TPACK in chemistry education (Deng et al., 2017; Gong et al., 2023; Zimmermann et al., 2021). Based on previous studies that discuss TPACK, there has been no research on Bibliometric analysis of TPACK in chemistry education.

Considering the above, this work seeks to close the research gap by conducting a comprehensive bibliometric analysis of the literature on TPACK in chemistry education. Scopus articles were chosen as the basis for conducting the bibliometric analysis. This analysis can determine which research topics receive the most publications and, in the future, which "TPACK chemistry education" topics present prospects for further research. The process for conducting the analysis is bibliometric analysis, which includes the stages of implementing a tool based on the Scopus database through the website www.scopus.com.

2. Methodology

Bibliometric analysis was used to conduct this research (Donthu et al., 2021; Garza-Reyes, 2015; Kurniati et al., 2022; Nandiyanto et al., 2023; Zhang et al., 2021). Data in the form of 22 articles were obtained from the Scopus database through the www.scopus.com page using the keyword search "TPACK chemistry education". The data that has been obtained is arranged in RIS format, then analyzed using VOSviewer (van Eck & Waltman, 2010). VOSviewer is used for citation analysis, co-occurrence analysis, and co-authorship analysis (Arsi Prabaningtias et al., 2022). To enrich the science of mapping, network analysis using clustering and visualization was conducted (Donthu et al., 2021). Hierarchical clustering is used to analyze clustering, while visualization analysis uses network visualization, overlay visualization, and density visualization (Al Husaeni & Nandiyanto, 2021; Martínez-López et al., 2020; Shukla et al., 2020; van Eck & Waltman, 2010). Some literature states that there are five steps to conduct a bibliometric analysis (Fahimnia et al., 2015; Setyaningsih et al., 2018; Tranfield et al., 2003) as presented in Figure 1.

Figure 1. Steps of bibliometric analysis

3. Results and Discussion

3.1 Output Publication and Citation Structur

The keyword "TPACK chemistry education" was used to conduct a literature search in the Scopus database because the database has several good quality literatures. Initially, by selecting the keyword, it was written in the document sub-section, namely the search document. The format of "article title, abstract, keywords" in the Scopus database was chosen to find more literature. The results of the literature search can be seen in Table 1.

Table 1. Search Data Matrix

Matrix Data	Search
Source	TPACK chemistry education
Publication year	2011-2022
Paper	22
Citation	208
Cite/year	17,33
Author/paper	1,00
h-indeks	7
g-index	14
hI,norm	7
hI,annual	0,58
hA-index	4

Based on Table 1, the literature data obtained were 22 articles relevant to the research with the keyword "TPACK chemistry education" which had the most citations. The most citations can be seen in Table 2 (top 10 articles cited).

Table 2. Top 10 cited articles

Year	Title	Source	Cites	Type
2011	New Pedagogies on Teaching Science with Computer Simulations (Khan, 2011)	Journal of Science Education and Technology	80	Article
2017	Examining the validity of the technological pedagogical content knowledge (TPACK) framework for preservice chemistry teachers (Deng et al., 2017)	Australasian Journal of Educational Technology	34	Article
2017	I like Facebook: Exploring Israeli high school chemistry teachers' TPACK and self-efficacy beliefs (Blonder, 2017)	Education and Information Technologies	21	Article
2014	Learning How to Teach Chemistry with Technology: Pre-Service Teachers' Experiences with Integrating Technology into Their Learning and Teaching (Chittleborough, 2014)	Journal of Science Teacher Education	15	Article
2020	A systematic review of 3D printing in chemistry education - Analysis of earlier research and educational use through technological pedagogical content knowledge framework (Pernaa, 2020)	Chemistry Teacher International	14	Review
2020	Embracing Digital Technology in Science Classrooms—Secondary School Teachers' Enacted Teaching and Reflections on Practice (Walan, 2020)	Journal of Science Education and Technology	12	Article
2021	Developing Prospective Chemistry Teachers' TPACK-A Comparison between Students of Two Different Universities and Expertise Levels Regarding Their TPACK Self-Efficacy,	Journal of Chemical Education	11	Article

	Attitude, and Lesson Planning Competence (Zimmermann et al., 2021)			
2019	Current trends in TPACK research in science education: A systematic review of literature from 2011 to 2017 (Setiawan, 2019)	Journal of Physics: Conference Series	5	Conference Paper
2020	Modeling meaningful chemistry teacher education online: Reflections from chemistry preservice teacher educators in australia (Carpendale et al., 2020)	Journal of Chemical Education	4	Article
2015	Twenty-First Century Skills: Using theWeb in Chemistry Education (Apotheker, 2015)	Chemistry Education: Best Practices, Opportunities and Trends	4	Book Chapter

Analysis of publication and citation trends from 2011-2022 to see the development of publications increased slightly from 2018-2020. But experienced a decline in 2020-2023. In 2012, 2013, 2016, and 2018 no articles were published, while the most publications were made in 2020 as many as 6 articles. On the other hand, citations to articles increased in 2018-2022. However, the development of citations related to articles tends to fluctuate in 2011-2018. The most citations in 2022 were 46 citations and the lowest citations in 2015 with 1 citation. In 2012 there was 1 article published, but the article was not cited in the range 2012-2023 (search on April 3, 2023). Data related to publication and citation trend analysis can be seen in Figure 2.

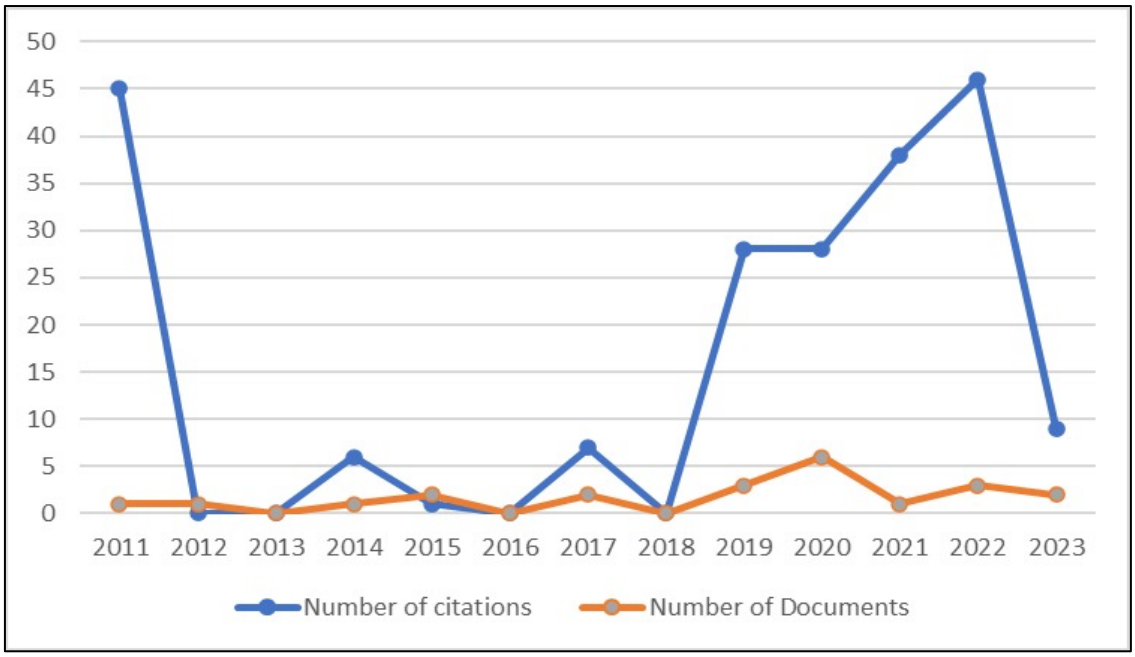


Figure 2. Publication and citation trends in the Scopus database (search on April 3, 2023)

The data network visualization displays on scopus data related to the keyword "TPACK chemistry education" can be seen in Figure 3, Overlay visualization can be seen in Figure 4, and density visualization can be seen in Figure 5.

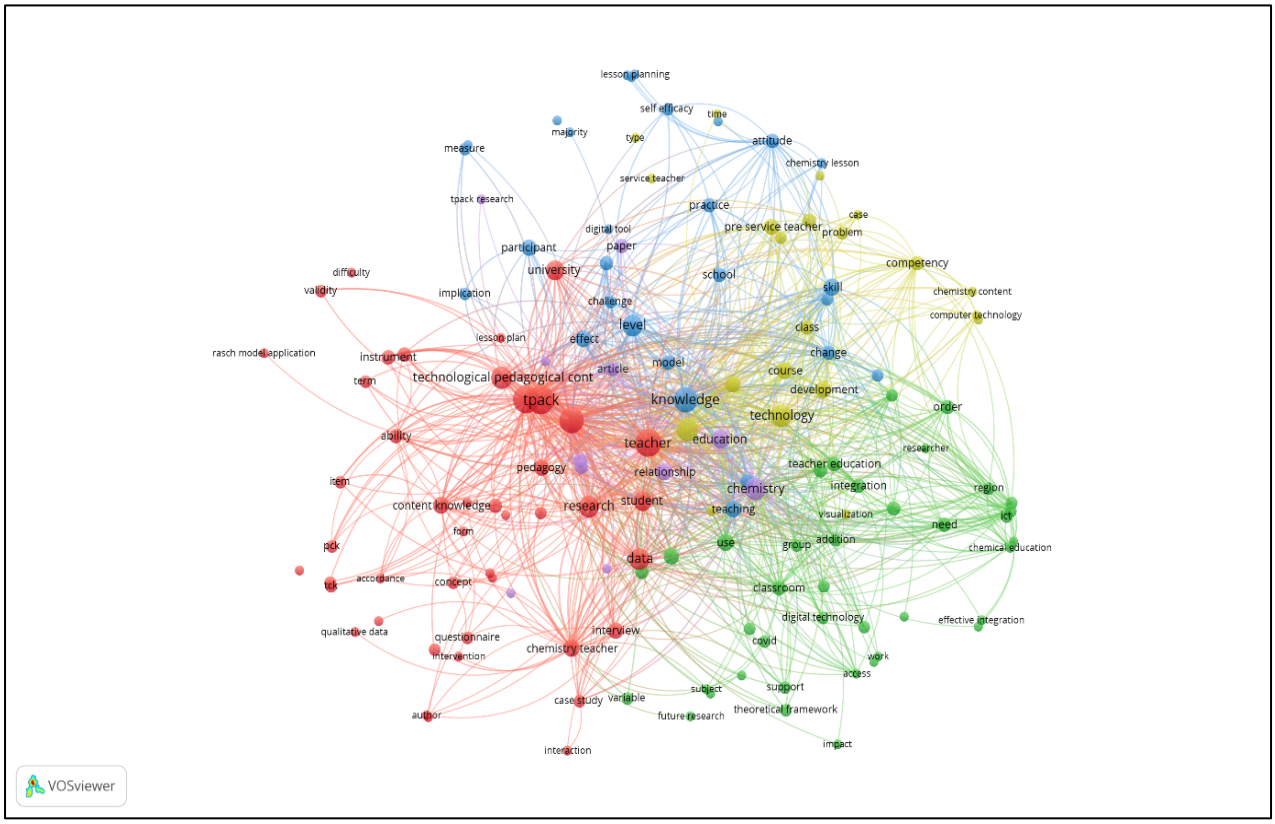


Figure 3. Network visualization

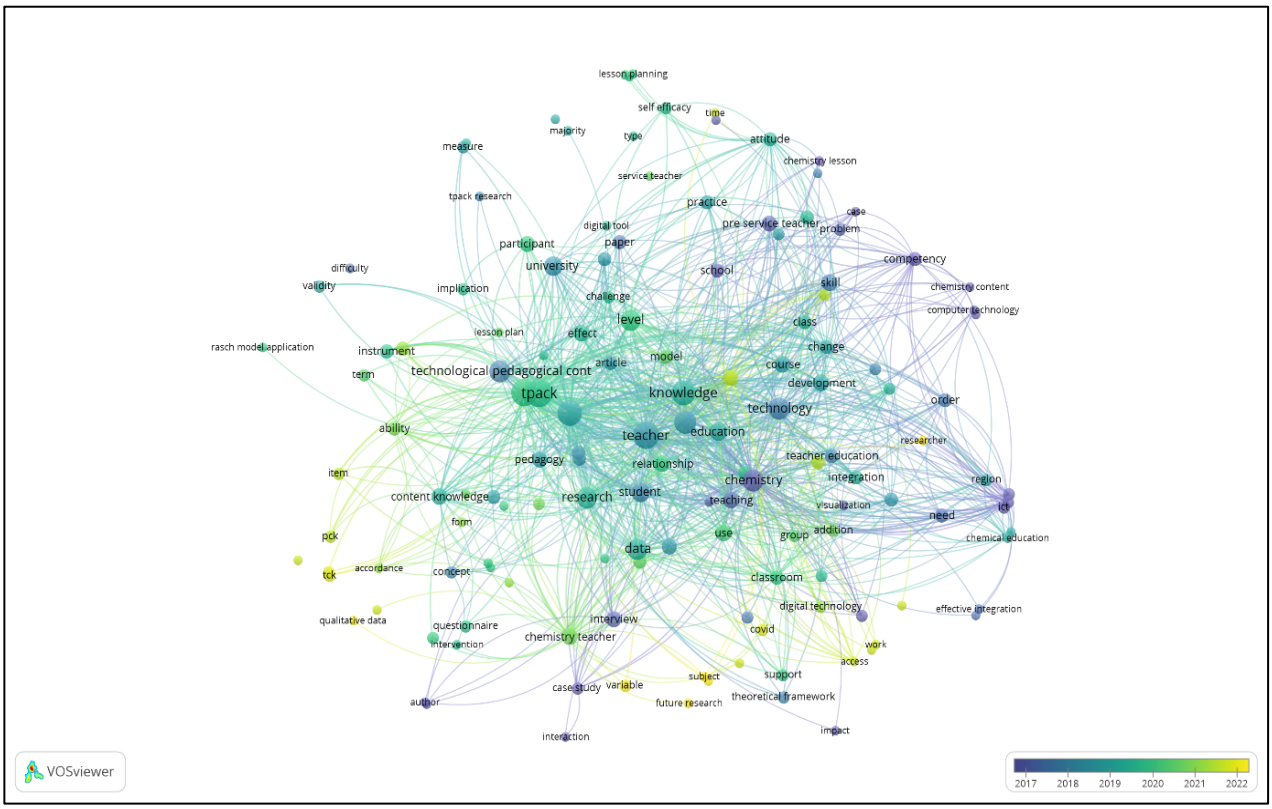


Figure 4. Overlay visualization

Figure 5. Density visualization

Overlay visualization analysis and density visualization were used to find significant themes within each study or research theme. These findings were obtained by calculating the co-occurrence of keyword pairs. VOSviewer software was used to perform the analysis. As can be observed, each cluster is associated with other terms. This indicates that the progress of studies on this subject is connected. In addition, network analysis allows the identification of Authority Authors. Cluster results are presented in Table 3.

Table 3. Keywords representing each cluster

No	Kluster	Elemen
1	Kluster 1 (44 item)	ability, accordance, analysis, assessment, author, case study, chemistry teacher, computer simulation, concept, content knowledge, data, delivery, difficulty, form, indonesia, instrument, interaction, intervention, interview, item, lesson plan, pck, pedagogy, perspective, pre service chemistry teacher, qualitative data, questionnaire, rasch model application, research, stage, student, study, tck, teacher, technological pedagogical, technological pedagogical content knowledge, term, tpack, tpack component, tpack framework, tpk, university, validity, video
2	Kluster 2 (39 item)	access, addition, chemical education, chemistry teaching, classroom, communication technology, covid, digital technology, effective integration, field, framework, future research, group, ict, impact, improvement, information, integration, learning process, need, order, pedagogical knowledge, process, recommendation, reflection, region, researcher, subject, support, teacher education, technological, technological knowledge, theoretical framework, topic, understanding, use, use, way, work

3	Kluster 3 (28 item)	attitude, challenge, change, chemistry education, chemistry lesson, digital tool, effect, future teacher, implementation, implication, knowledge, lesson planning, level, majority, measure, model, participant, perception, practice, preservice chemistry teacher, requirement, school, self efficacy, seminar, skill, teaching, teaching practice, university seminar
4	Kluster 4 (21 item)	case, chemistry content, class, competency, computer technology, content, course, development, future, learning, opportunity, preservice teacher, preparation, preservice teacher, problem, sample, service teacher, technology, time, type, visualization
5	Kluster 5 (11 item)	article, biology, chemistry, education, paper, physics, relationship, systematic review, technological content knowledge, technological pedagogical content knowledge framework, tpack research

The author connection analysis describes the analysis of the general author and the network as it relates to patterns of collaboration between people. Each node in this network represents an author in relation to their writing. This analysis can incorporate many different dimensions to show clustering and correlations between dimensions or changes over time. Analyze the author network from the author's birth year to the present. In this scenario, author connections may be classified as annual connections. It has been established that Yamtinah, S., is the most numerous authors. In addition to analyzing co-authors, it is possible to examine all authors of articles and procedures related to TPACK chemistry education, as seen in Figure 6. The examination of authors against the number of documents is depicted in Figure 7.

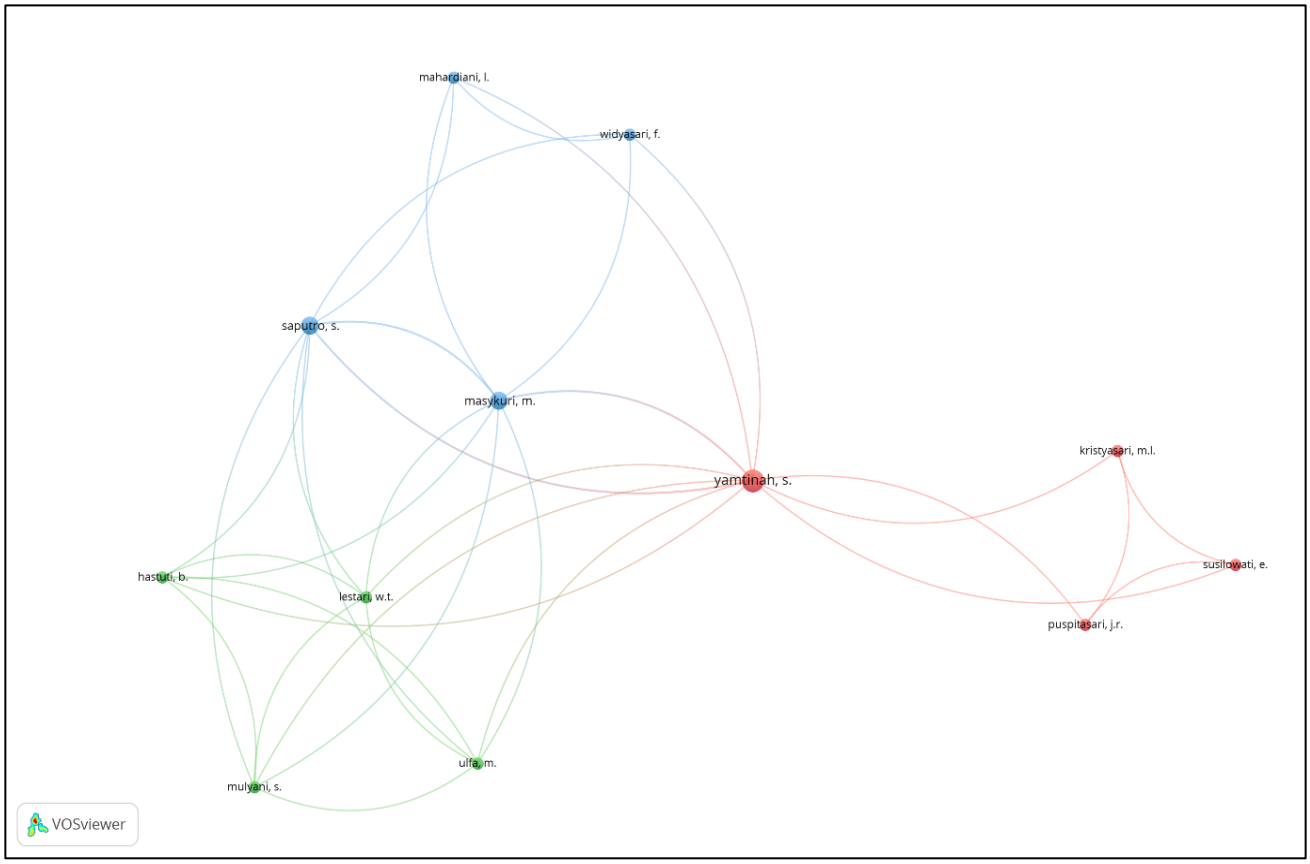


Figure 6. Author connection analysis

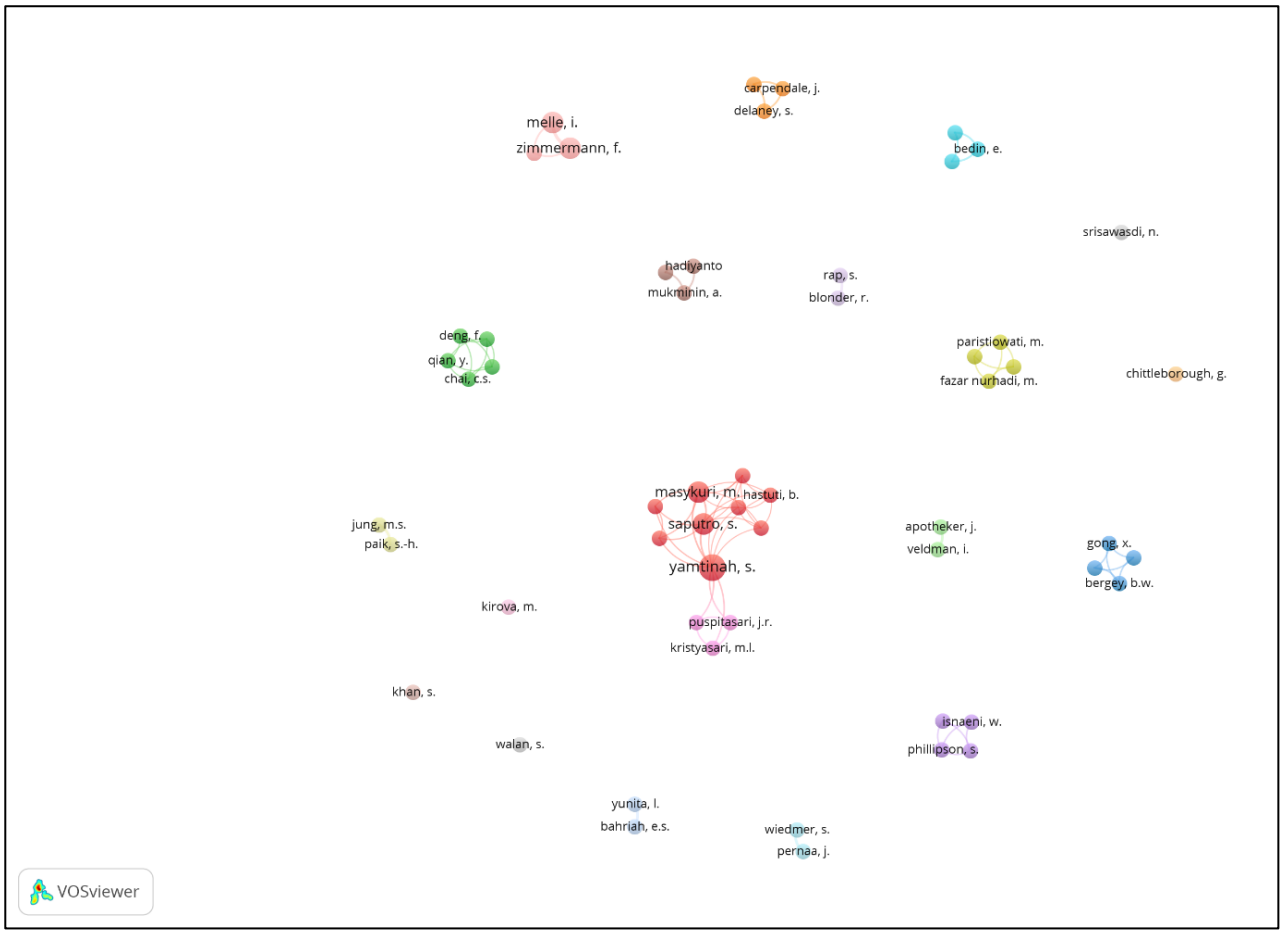


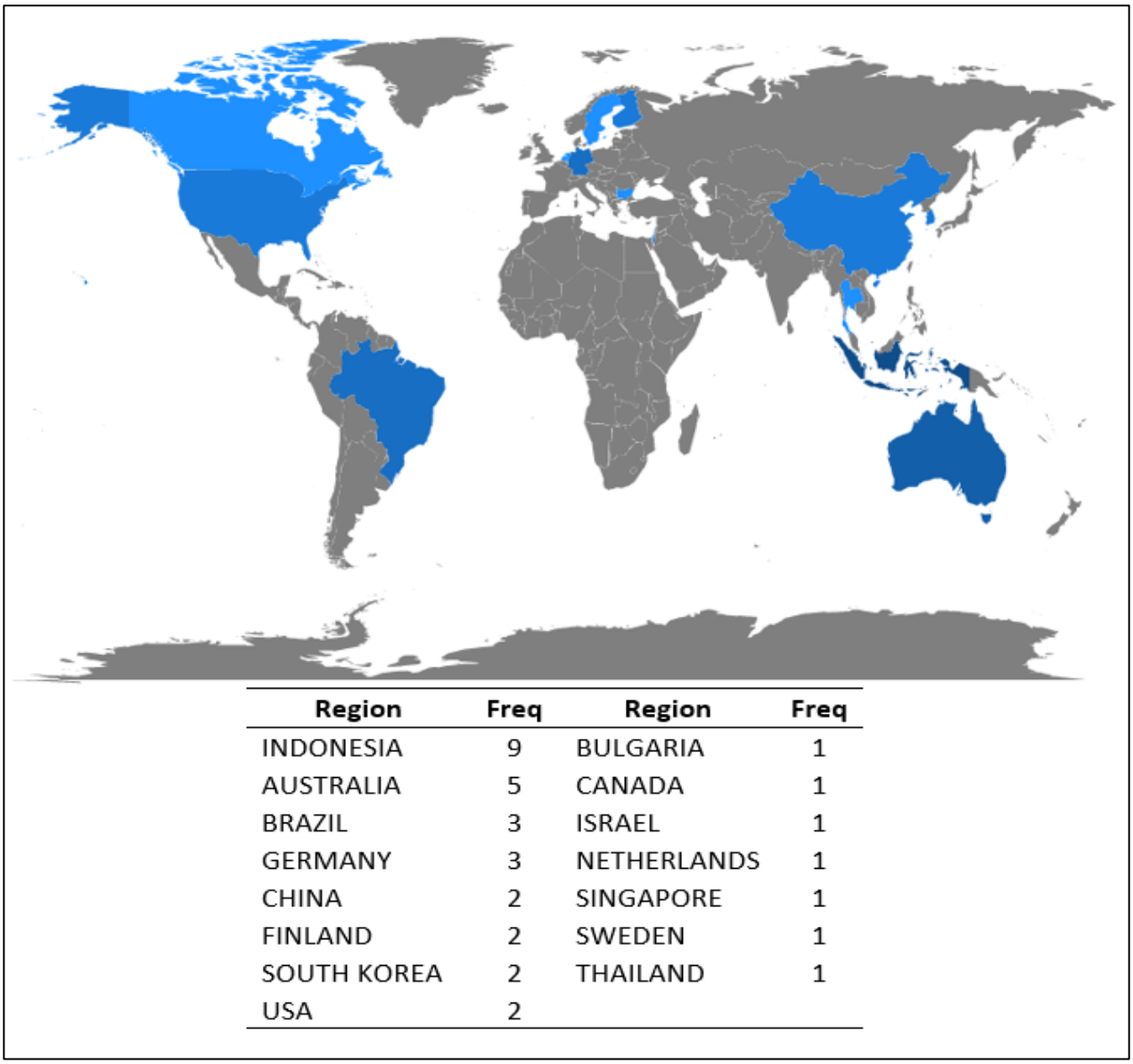
Figure 7. Author analysis by number of documents

3.2 Research Statistics

Literature data downloaded from the page www.scopus.com with the keyword "TPACK chemistry education" in the form of BibTex, then analyzed using the RStudio application using the command "bibliometrix and biblioshiny" to determine the productivity of the authors, obtained by Indonesia with the highest author of 9 authors and the lowest in Bulgaria, Canada, Israel, Netherland, Singapore, Sweden, and Thailand with 1 author each. The productivity of authors from various countries can be seen in Figure 8.

Conclusion

Based on the results and discussion above, it can be concluded that TPACK research in the field of chemistry education from 2011-2023 is still very limited. 22 article papers were published. This study collected data from various research topics that are interconnected with each other. This article used bibliometric analysis to display various literatures to find major themes in each research or topic. According to the findings of this study, there are 5 clusters in the VOSviewer viewer. Cluster 1 (44 items), cluster 2 (39 items), cluster 3 (28 items), cluster 4 (21 items), and cluster 5 (11 items). Two limitations apply to this study. First, these studies are usually limited by the small number of keywords collected and by the Scopus database used to collect the articles. Secondly, subjective judgment of the authors occurs and may continue to produce errors. Future studies are advised to expand the sample size by increasing the keywords used and creating a more accessible database. In addition, it can be used to compare the findings of other bibliometric analyses.



Region	Freq	Region	Freq
INDONESIA	9	BULGARIA	1
AUSTRALIA	5	CANADA	1
BRAZIL	3	ISRAEL	1
GERMANY	3	NETHERLANDS	1
CHINA	2	SINGAPORE	1
FINLAND	2	SWEDEN	1
SOUTH KOREA	2	THAILAND	1
USA	2		

Figure 8. Country Scientific Production Author

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