GLOBAL TREND ON MIXED REALITY AND CHEMICAL THINKING: A BIBLIOMETRIC ANALYSIS

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Abstract

This study aims to provide a comprehensive overview of the bibliometrics approach to analyse the global trend in mixed reality (augmented reality and virtual reality) and chemical thinking. This study comes from 274 collected papers that Scopus indexed concerning mixed reality and chemical thinking from 2014 to 2023. We used VOSviewer for bibliometric analysis. In general, global trend research on mixed reality has increased in the number of papers and the number of citations. This shows that research on mixed reality is an interesting research area. However, the number of papers on chemical thinking research from 2014 to 2022 is very small but the number of citations has shown a continuous increase. At the beginning of 2023, there is no paper on chemical thinking research, but the number of citations is 115. The results of this study provide an overview and opportunities for carrying out future research.

Keywords: Augmented reality, Chemical thinking, Chemistry, Mixed reality, Virtual reality.

1. Introduction

This paper provided a detailed overview of the present current state and global trend research about mixed reality and chemical thinking. In this study, we used the term mixed reality to cover applications of both augmented reality and virtual reality. The term mixed reality can be used to cover applications of both augmented reality and virtual reality [1].

Many reports have discussed augmented reality and virtual reality, i.e., developing augmented reality as teaching material on chemistry learning [2-4]. Previous research also reported the review of the advantages and applications of augmented reality [5], the use of virtual reality as a learning tool for chemistry learning and chemistry laboratory activity [6-9], and a review of the application of virtual reality [10, 11]. Based on the above literature, there is no report on the global trend of mixed reality and chemical thinking.

We reported a bibliometric analysis of mixed reality and chemical thinking published from 2014 to 2023. We selected patterns on research trends and the correlation between mixed reality and chemical thinking. The novelties of this study are the focus of the bibliometric analysis to point out: (i) how is the situation of mixed reality and chemical thinking research in one last decade? In terms of the usage of keywords in publication; (ii) Is there any correlation between mixed reality and chemical thinking? (iii) What are the future research opportunities on mixed reality and chemical thinking?

2. Method

This research is based on systematic quantitative research. To evaluate the literature about mixed reality and chemical thinking, we employed bibliometric analysis to assess search results in Scopus. A literature search was conducted in February 2023. The literature search process can be seen in Fig. 1.
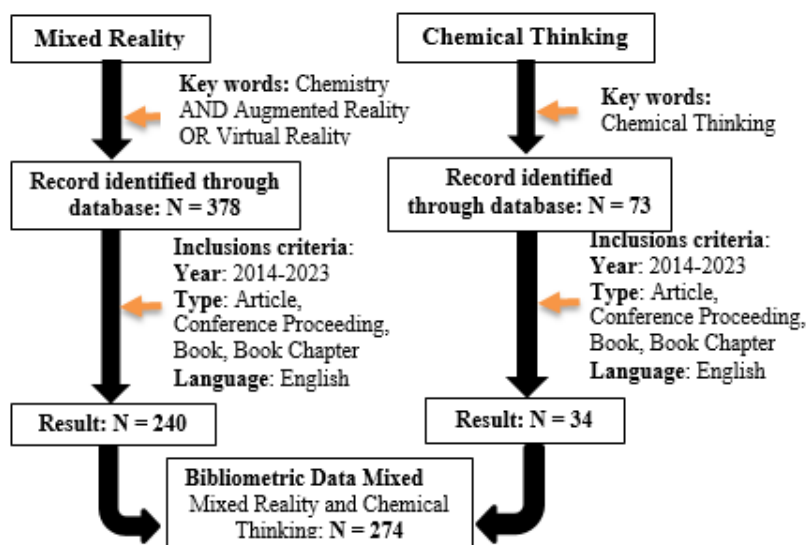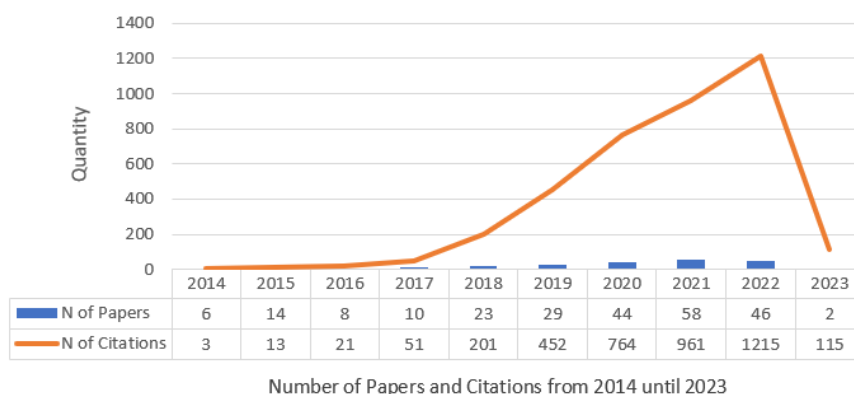

Fig. 1. The literature search process.

The first literature search with keywords "Chemistry AND Augmented Reality OR Virtual Reality" contains 378 pieces of literature that are relevant to chemistry and augmented reality or virtual reality. After setting the criteria for inclusions: the period from 2014 to 2023, type of literature including article, conference proceeding, book, book chapter, and the language in English, the result is 240 literature. The second literature search with the keywords "Chemical Thinking" contains 73 kinds of literature relevant to chemical thinking. After setting the criteria for inclusions: the period from 2014 to 2023, type of literature including article, conference proceeding, book, book chapter, and the language in English, the result is 34 kinds of literature. The total number of pieces of the literature analysed in this study is 274 kinds of literature. In this study, sample articles retrieved in RIS format from Scopus are processed using VOS viewer software to aid visualization and identify trends [12, 13]. The VOS viewer can inspect the distribution of publications by year, country and universities, trends in publishing time, and research fields [14], and also can be used to evaluate the relationship between publications or journals in terms of citations, the collaboration between scholars, and the relationship in terms of joint emergence between scientific papers [15].

3. Results and Discussion

378 papers were found from the literature search process with keywords "Chemistry AND Augmented Reality OR Virtual Reality" and 240 papers were collected after setting inclusion criteria specific to the year from 2014 to 2023, type of literature including article, conference proceeding, book, book chapter, and the language in English. 138 papers were excluded. The global research trend on mixed reality (augmented reality and virtual reality) can be seen from the chart number of papers vs the number of citations (see Fig. 2).

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
N of Papers	6	14	8	10	23	29	44	58	46	2
N of Citations	3	13	21	51	201	452	764	961	1215	115

Number of Papers and Citations from 2014 until 2023

Fig. 2. Number of paper vs number of citation research on mixed reality.

In 2014, there were very few papers on mixed reality with only 6 papers and only 3 citations. In 2015 the number of mixed reality papers increased to 14 but decreased in 2016 (8 papers) and 2017 (10 papers). From 2018 to 2021 the number of papers on mixed reality continues to increase, then slightly decreases in 2022, while the number of citations continues to increase. Although the number of papers has increased and decreased from 2014 to 2022, the number of citations has shown a continuous increase from 2014 to 2022. At the beginning of 2023, there were 2

papers on mixed reality and 115 citations. This shows that research on mixed reality is an interesting research area. The most prominent keywords are in Table 1. Table 1 shows that the most prominent keywords in mixed reality research are Augmented Reality (Freq: 167), while Virtual Reality is in 3rd place (Freq: 48). The most prominent affiliation is in Table 2. Table 2 shows that the most prominent affiliation on mixed reality research is Universitas Negeri Malang. The most prominent country for mixed reality research is the US (52 papers). The second country has Indonesia (23 papers). China has 20 papers, Germany has 15 papers, and Taiwan has 15 papers. This finding shows that research about mixed reality is also popular in Asian countries, especially Indonesia, China, and Taiwan.

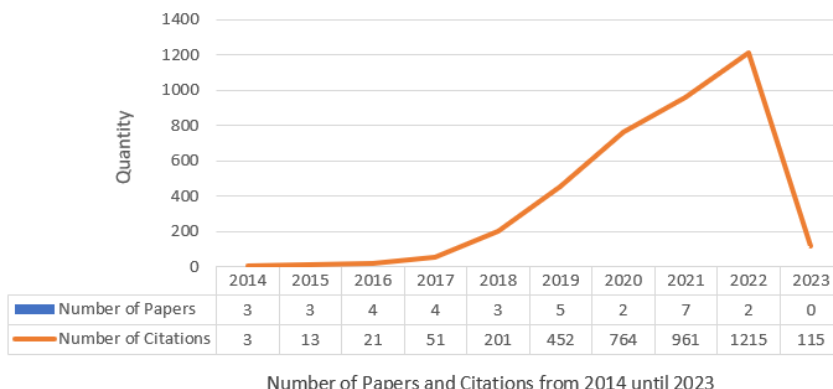**Table 1. The most prominent keywords in mixed reality research.**

Name	Freq.
Augmented Reality	167
Student	59
Virtual Reality	48
Chemistry	47
Education	29
Chemistry Education	24
E-learning	24
Augmented Reality Technology	23
Human	23
Engineering Education	21

Table 2. The most prominent affiliation on mixed reality research.

Affiliation	Freq.
Universitas Negeri Malang	7
National University of Singapore	5
Swiss Institute of Bioinformatics	5
École Polytechnique Fédérale de Lausanne	5
Universidade Nova de Lisboa	5
Instituto Superior Técnico	4
National Taiwan Normal University	4
UIN Sunan Gunung Djati	4
Kryvyi Rih State Pedagogical University	4
University Kebangsaan Malaysia	3

Seventy three papers were found from the literature search process with keywords "Chemical Thinking" and 34 papers were collected after setting inclusion criteria period from 2014 to 2023, type of literature including article, conference proceeding, book, book chapter, and the language is English. 39 papers were excluded. Global research trends on chemical thinking can be seen from the chart number of paper vs number of citations (see Fig. 3). Based on Fig. 3, there were very few papers on chemical thinking research from 2014 until 2022. There are

only 2 to 7 papers each year. Although the number of papers on chemical thinking research from 2014 to 2022 is very small, the number of citations has shown a continuous increase from 2014 until 2022, from 3 to 1215 citations. At the beginning of 2023, there is no paper on chemical thinking research, but the number of citations is 115. This shows that research on chemical thinking has a very good opportunity to be carried out.

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Number of Papers	3	3	4	4	3	5	2	7	2	0
Number of Citations	3	13	21	51	201	452	764	961	1215	115

Number of Papers and Citations from 2014 until 2023

**Fig. 3. Number of paper vs number of citation on chemical thinking.**

The most prominent affiliation on chemical thinking research is The University of Arizona (7 papers). The 2nd – 10th placed by the University of Massachusetts Boston (6 papers), University of Michigan, Ann Arbor (4 papers), Boston Public Schools (3 papers), Malmö Högskola (2 papers), Purdue University (2 papers), Interfacultair Centrum voor Lerarenopleiding, Onderwijsontwikkeling en Nascholing (2 papers), University of Iowa (2 papers), Infometrix, Inc. (1 paper), and Hingham (1 paper).

The US is the most prominent country that published papers discussing chemical thinking (23 papers). While other countries only have a few papers. The second and third place by the Netherlands and Sweden, both countries have 3 papers. Brazil has 2 papers. The other country has only 1 paper from Australia, France, Greece, Iraq, Italy, and Mexico. This finding shows a great opportunity for research on chemical thinking.

274 articles were obtained from the literature search process (see Fig. 1), the results are compiled in Research Information Systems (RIS) format to include all important article information such as the titles, author and affiliation names, abstracts, keywords, and references using Mendeley software. RIS data were analysed using VOSviewer. The overlay visualization is shown in Fig. 4 and the visualization of density keywords mixed reality and chemical thinking is shown in Fig. 5. Mixed Reality is research that is currently developing in chemistry learning. This topic begins to be researched around 2021. Figure 4 shows that chemical thinking is a skill that correlates with the use of mixed reality.

Figure 5 shows that mixed reality keywords have a strong correlation with visualization and attitude keywords. This can be interpreted that mixed reality helps visualize abstract chemical concepts to improve attitudes, student achievement, and learning performance. In addition, the thinking skill that has a large frequency density related to Chemistry learning is chemical thinking. Chemical thinking skills are required in all chemistry materials. In density visualization, it can be seen that

the topic of chemical bonds is a topic that has a strong correlation with mixed reality and chemical thinking. This shows the urgency of implementing mixed reality and chemical thinking in the chemical bond topic. The chemical bond topic is quite complex because it consists of several sub-chapters. Not many studies have focused on one type of chemical bond to deepen and broaden the discussion given to students. This opens opportunities for research and development of mixed reality and chemical thinking on the sub-topic of chemical bonds, such as ionic bonds. This result confirms the effectiveness of bibliometric analysis [16-25] in exploring and visualizing the trend literature that can be used as a consideration for deciding further research.
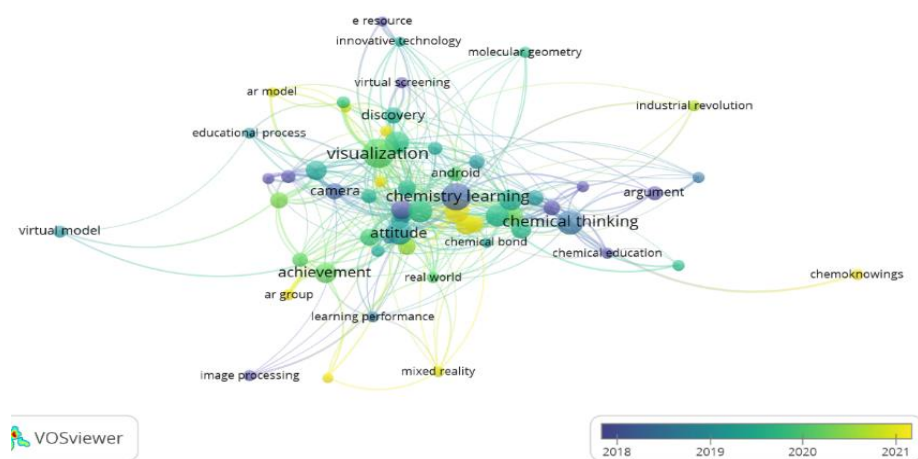
Fig. 4. Visualization of overlays using VOS viewer.
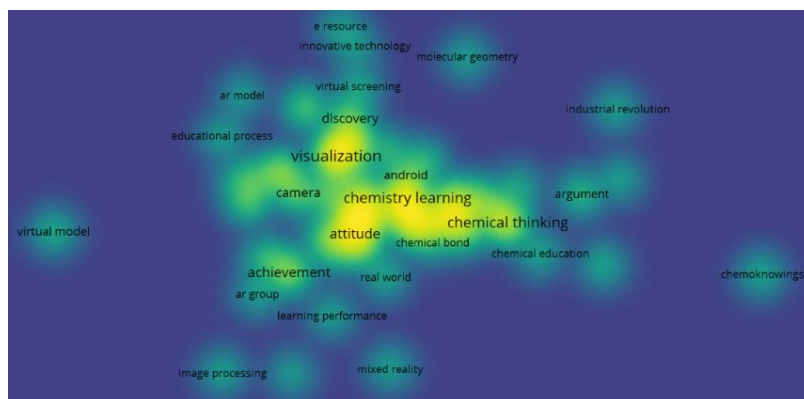
Fig. 5. Visualization of density keywords mixed reality and chemical thinking

4. Conclusion

Based on the result of this study, we can conclude that mixed reality and chemical thinking are two research topic that increasingly interested. It can be seen from the number of citations that has increased continuously in the last decade. Chemical thinking is a skill that correlates with the use of mixed reality. There is a great

opportunity for research on mixed reality which relates to the measurement of chemical thinking skill.

Acknowledgements

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