JPII 11(1) (2022) 73-90

Jurnal Pendidikan IPA Indonesia

http://journal.unnes.ac.id/index.php/jpii

A BIBLIOMETRIC ANALYSIS ON HOW ORGANIC CHEMISTRY EDUCATION RESEARCH HAS EVOLVED COLLABORATIVELY OVER TIME

N. M. H. Nik Hassan[1], Othman Talib*[2], Tenku Putri Shariman[3], N. A. Rahman[4], A. A. M. Zamin[5]

[1,2,4]Universiti Putra Malaysia, Malaysia
[3]Multimedia University, Malaysia
[5]International Islamic University Malaysia, Malaysia

DOI: 10.15294/jpii.v11i1.34185

Accepted: December 29th 2021. Approved: March 30th 2022. Published: March 31st 2022

ABSTRACT

Organic chemistry is widely regarded as a challenging topic; generally, students prefer to memorize rather than critically analyze concepts resulting in meaningful learning. In recent years, the curriculum of the organic chemistry subject has been reshaped and redefined to overcome the difficulties that students often experience while trying to understand the syllabus. The goal of this research is to illustrate the organic chemistry education's current trends, which adopted the bibliometric analysis method. A holistic review was carried out on organic chemistry education articles obtained from the Scopus database between the year 2011 up to 2020. Based on the keywords of "organic chemistry" and "education", the study has accumulated 1056 papers for further evaluation. Various tools have been implemented, for example, Microsoft Excel was used to conduct the frequency analysis, VOSviewer for data visualization, as well as Harzing's Publish or Perish in regard to citation metrics and analysis. Bibliometric indicators were employed to report the findings in this study, for instance, language, subject area, research trends by year of publication, top countries, top influential institution, active source title, citation analysis, authorship analysis and keywords analysis. The results show an increasing growth rate of literature on organic chemistry education from 2011 until 2020. The United States was the top contributor to organic chemistry education research, followed by Canada. Healthy collaboration exists across researchers, countries, and institutions. This evolvement of organic chemistry education reflects a rising emphasis on Science, Technology, Engineering and Mathematics (STEM) discipline incorporated into the 21st-century curriculum to prepare the desired workforce.

Keywords: bibliometrics; citation analysis; organic chemistry education; Scopus database

INTRODUCTION

The division in chemistry between organic and inorganic disciplines transpired historically. Whereas the difference between the organic and inorganic discipline was undefinable, the division was still considered a vital force until the middle of the nineteenth century (Okuyama & Maskill, 2013). In particular, organic chemistry was distinguished as a branch of chemistry related to organic chemicals that are found in living things like plants and animals, while inorganic chemistry is concerned with inorganic chemical compounds from non-carbon-based elements such as rocks, metals, or minerals (Chaloner, 2015; Smith, 2020).

Organic chemistry's significance in humanity cannot be underestimated in today's world. Note that this field has grown quickly in recent years, from dentists, pharmacologists, veterinarians, environmental chemists, forensic analyzers,

***Correspondence Address**
E-mail: otalib@upm.edu.my

and chemical engineers to the manufacture of everyday products including plastics, cosmetics, meals, medicine, pharmaceuticals, fertilisers, and fuels. As a result, organic chemistry education must evolve in tandem with current trends in order to remain relevant and appealing.

Basically, the organic chemistry course is often offered after general chemistry is taken as a pre-requisite course in most countries. Most organic chemistry textbooks follow the functional group approach that was established by Morrison and Boyd (Morrison & Boyd, 1959; DeCocq & Bhattacharyya, 2019). From 2010 to the present, many research reports about students' difficulties and misconceptions about organic chemistry, including their misunderstanding of the electron pushing formalism (Grove et al., 2012b; Bodé et al., 2019). Students' performance in organic chemistry has been declining over recent years, and they tend to learn through rote memorization. Organic chemistry has a high cognitive demand due to the abstract nature of its contents, making it overwhelming for students (Galloway et al., 2017; O 'Dwyer & Childs, 2017). Thus, the reduction of teaching challenges is advocated to help overcome students' failure in organic chemistry. In view of that, a new curriculum and reorganization of materials for the organic chemistry curriculum are really needed to improve students' reasoning of each reaction, hence making students complete the course having greater interpretation of organic chemistry and reactivity (Webber & Flynn, 2018). By analysing the most commonly used keywords in articles on organic chemistry education, it is possible to determine whether the most commonly used keywords in articles on organic chemistry education have already been adequately explored and whether there are opportunities to learn about new topics that are relevant for further exploration. The relevance of a specific topic can be measured by the frequency with which the keywords appear in the documents (de Oliveira et al., 2019).

Some systematic reviews related to organic chemistry can be found in the literature, but the focus was confined to particular concept in chemistry. Previous researcher such as Mazzuco et al. (2022) and Nugraheni et al. (2020) limit their work to systematic literature review (SLR) and systematic meta review by investigating the sources from all chemistry courses. Meanwhile, Lathwesen and Belova (2021) had employed SLR that included STEM education domains containing biology, mathematics, physics, chemistry, and science education. Correspondingly, the capacity of these literature review to gauge enormous volumes of diverse literature remains limited (Verrall & Pickering, 2020). In the other hand, few studies have highlighted research trends and identified the most relevant topic or keywords, the international collaboration network and gaps in the research topic of study (Table 1). Yet, no literature review on organic chemistry education uses a bibliometric analysis to evaluate the progress in the field. In response to these problems, bibliometrics measurement are employed to assess the publication activity on organic chemistry education and reveal gaps in the literature which might support the scientific demand and novelty of study.

Furthermore, the future emerging of research areas can be identified as the research trends usually leads to curriculum development and transformation. Hence, this article offers an organic chemistry education bibliometric analysis of by focusing on three main research questions (RQs): RQ1: How has organic chemistry education research evolved and been distributed?; RQ2: What are the key topic areas that have been discussed in organic chemistry education research?; RQ3: Who are the major participants in organic chemistry education research, and how have they collaborated?

A bibliometric research is becoming more evident as a method of demonstrating the studies' trends (Ahmi & Mohamad, 2019). Several bibliometric studies associated with organic chemistry research were performed in the past (Table 1). Moreover, Evdokimenkova and Soboleva (2020) presented the bibliometric analysis of 26958 publications with Russian affiliation that were published for the last 30 years under the category of "organic chemistry" from the Web of Science database. They determined the change dynamics in the preferable journals for publications, the most productive organizations, the citation scheme, as well as publication activity. They also issued publication fractions in foreign and domestic journals, trends in research areas, and international collaboration assessment for organic chemistry in Russia. Also, they identified that most organic chemistry research that was published in domestic journals possess low citations, and this pattern has been present since 2018. Apart from that, almost half of Russian research (50%) was documented in international journals, which resulted to high citation rates.

The study utilised the same scope to compare these four-letter publications. Because all of the publications reviewed are major journals in the field of organic chemistry, the results have benefited organic chemists to choose where to submit their works for publication. The study offered researchers with an overview as well as publications comparative analysis when they are required to make a decision by comparing letters journals in bibliometric analysis. In addition, Garg and Pooja Kumari (2018) reviewed a bibliometrics study focusing on doctorate theses approved by the Department of Chemistry, Aligarh Muslim University, Aligarh (AMU) between 1935 and 2014. They looked at how well the research investigations mentioned in the doctorate theses because the research quality in a dissertation or thesis can vary greatly from nation to country, university to university, and even supervisor to supervisor. They concluded that the number of PhD theses submitted to AMU's chemistry department was minimal at first, but began to rise after 1960. Furthermore, the sub-discipline of organic chemistry received the most theses, followed by inorganic and physical chemistry. This suggests that research in the field of organic chemistry has expanded in recent years.

Table 1. Past Articles on Bibliometric Analysis and Organic Chemistry-Related Studies

Author	Evdokimenkova and Soboleva (2020)	Tomaszewski (2020)	(Garg and Pooja Kumari (2018)
Domain/ Search Strategy	"organic chemistry"	Letter Journal: Bioorganic & Medicinal Chemistry Letters, Letters in Organic Chemistry, Organic Letters and Tetrahedron Letters	doctoral theses accepted during the period of 1935-2014
Data Source & Scope	Web of Science Core Collection (WoS CC) 1990-2019	Web of Science Core Collection (WoS CC) and SciFinder 1999-2016	Shodhganga, a repository of Indian Electronic Theses and Dissertations 1935-2014
TDE	26958	20,675(BMCL), 1,732(LOC) 24,889(OL), 34,380(TL)	809
Bibliometric Attributes Examined	dynamics of publication activity in Russia over the past 30 years, citation scheme, most productive organizations, most preferable journals for publications, comparing publication fractions in domestic and foreign journals, and international collaboration assessment trends in research areas of organic chemistry in Russia	subscription rate, open access availability and article processing charge, field categories, language, maximum page length, citation style, peer-review type, review time, publication frequency, impact factor, journal h-index, acceptance rate, and database coverage	pattern of growth of theses accepted during the period of past 80 years, distribution of theses accepted by gender, and distribution of supervisors by number of students guided

*TDE: Total Documents Examined; BMCL : Bioorganic & Medicinal Chemistry Letters ; LOC : Letters in Organic Chemistry ; OL: Organic Letters ; TL : Tetrahedron Letter

METHODS

The research has considered the following aspects regarding the literature in organic chemistry education to answer the RQs of study. For the evolution and distribution of organic chemistry education, the languages of documents and the research trends over the years were observed across publications. From the major contributions in organic chemistry education research, several pertinent data were identified, including the top countries contributing to publications, the most influential institutions, the most active source titles, the citation, and authorship analysis. This study aimed to attain more understanding of organic chemistry education research trends, notably in regard to its international reach and cooperation. The current data will have to be screened in order for academicians to provide suggestions for future studies in the field of organic chemistry education research.

In performing systematic reviews of studies, the review utilised the updated Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standards (Zakaria et al., 2021). Figure 1 depicts the processes for identifying sources for the organic chemistry education review, as well as data analysis methodologies.

The Scopus index was chosen as the data repository for searching and extracting documents. Scopus generates precise citation search results and offers comprehensive coverage of resources for fields of study beyond physical sciences as well as medicine (Hallinger & Kovačević, 2019). This research uses data from the Scopus database as of 6th March 2021. The keywords utilised to search relevant articles associated with this research are "organic chemistry" and "education", which are frequently in the article's keyword list, abstract, and title. We did not pay attention to the titles of the publications since several laboratory experiments did not include the keywords organic chemistry or education in their titles; despite the fact that the article itself tackles a topic that is related to the research field and the study's goal. The Scopus search engine was used to find the terms "organic chemistry" and "education." Scopus subject filters were then employed. The scope of the search was limited to published journals and articles from 2011 to 2020 retrieved from the Scopus database. This allows the search engine to discover the earliest studies published in the literature in the past 10 years ago. In addition, the review had a limited reach in terms of document and source categories, with only papers and journals being included.

The scope and coverage in this study were based on the search field, time frame, source type, and document type to exclude irrelevant papers. This search yielded 1056 documents. Further exclusions were made based on subject relevance after examining the abstracts of all items in the list. Following the document screening, 1056 documents on organic chemistry education remained in the final database.

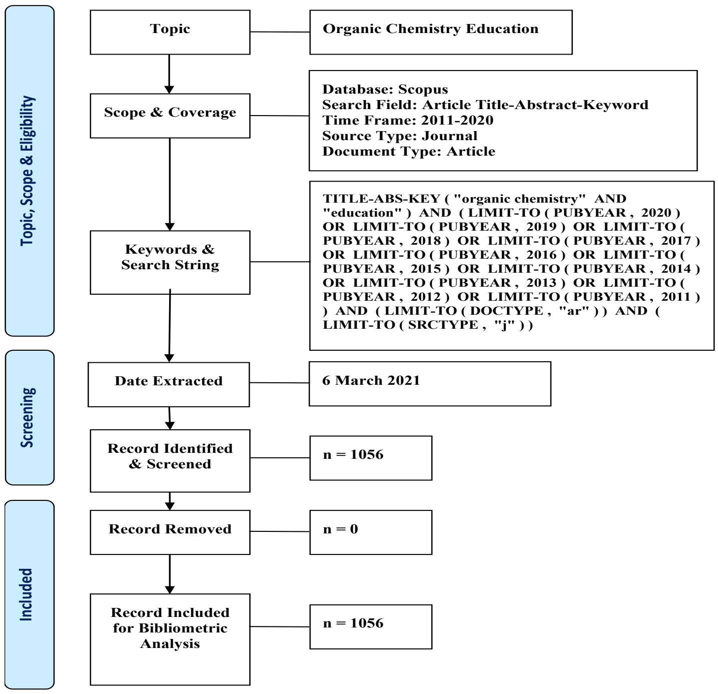

Figure 1. The Search Strategy Flow Diagram

The data was processed in a variety of methods to acquire the information needed to answer the RQs. Through the analyse search results tool, some findings were directly obtained from Scopus. Other findings were exported or manually inputted to a new Excel file. As part of the data sets, the data was exported in Research Information Systems (RIS) and Comma-Separated Values (CSV) formats. The file produced for all of the findings was evaluated for information such as percentages and cumulative percentages. In computing the citation metrics and some of the other frequencies, we utilised Harzing's Publish or Perish software. Additionally, the VOSviewer was utilised to visualize the bibliometric networks since it offers a freely available tool for constructing and visualizing the networks (Ahmi & Mohd Nasir, 2019). From this paper, the consequential observations on the tendencies in the literature on organic chemistry education will be further enriched and expanded.

RESULTS AND DISCUSSION

Referring to the data obtained from the Scopus database, the research design concentrated on analyzing the bibliometric attributes of documents such as languages, subject area, and research trends according to the year of publication, the most influential countries, institutions, and journals in organic chemistry education area. Most of the results are shown as percentage and frequency, while the co-occurrence of the author keywords, citation based on countries, co-authorship and co-citation are mapped using VOSviewer. The analysis of the data was divided according to the research questions (RQs). In answering RQ1, we had analyzed the publication trend in this area using the languages of documents and the research trends according to the year of publication. We calculated the data for this analysis using percentages and cumulative percentages from the data collected through the Scopus database.

Table 2 shows that English was the most common language, accounting for 96.89% of the total publications or 1029 publications on organic chemistry education research. The second most used language in publication was Spanish, but it was only reported for 0.94% of the total publications. The other documents were issued in 11 other languages, namely Russian, Croatian, Japanese, Chinese, Portuguese, French, Danish, German, Italian, Slovenian, and Turkish.

Table 2. Languages

Language	Total Publications (TP)*	Percentage (%)
English	1029	96.89%
Spanish	10	0.94%
French	4	0.38%
Portuguese	4	0.38%
Chinese	3	0.28%
Japanese	3	0.28%
Croatian	2	0.19%
Russian	2	0.19%
Danish	1	0.09%
German	1	0.09%
Italian	1	0.09%
Slovenian	1	0.09%
Turkish	1	0.09%
Total	**1062**	**100.00**

*One document has been prepared in dual languages

However, these languages accounted for only 0.38% and below. Generally, the papers which were published in English would have the plausible advantage of being encountered in the scientific community's journals due to English being the universal lingua franca in science. Because one document was published in dual languages, the total number of publications recorded for the language parameter was 1062 (see Table 2), which was more than the total number of publications between 2011 and 2020 (see Table 3).

Table 3. The Number of Organic Chemistry Education Research Publications by Year

Year	TP	NCP	TC	C/P	C/CP	*h*	*g*
2011	75	64	752	10.03	11.75	16	22
2012	83	78	3736	45.01	47.90	17	60
2013	92	86	1183	12.86	13.76	19	29
2014	88	82	1149	13.06	14.01	20	26
2015	129	122	1321	10.24	10.83	19	26
2016	90	87	1076	11.96	12.37	18	28
2017	106	93	665	6.27	7.15	14	18
2018	94	87	530	5.64	6.09	12	15
2019	115	94	458	3.98	4.87	11	13
2020	184	99	232	1.26	2.34	7	8
Total	1056						

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

Table 3 displays the publications number on organic chemistry education from the year 2011 to 2020. Note that three years had shown a sharp increase in publications during the ten years. The years were 2013, 2015, and 2017, with 92, 129, and 106 documents published during those years, respectively. With a total of 184 documents, the maximum productivity was recorded in 2020, while the lowest productivity was found in 2011, with a total of 75 documents. Generally, the number of publications increased between 2011 to 2020, reflecting the rising interest in organic chemistry research and its great potential for advancements. However, the citation volume of articles on organic chemistry education dropped slowly, starting from 2016 until 2020 (Figure 2).

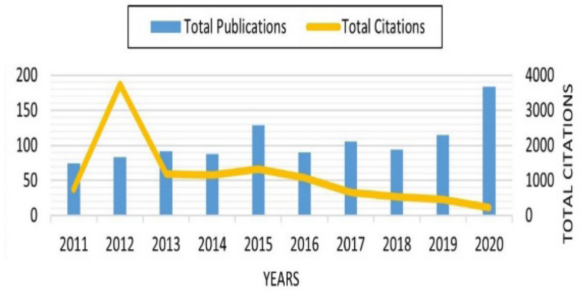

Figure 2. Total Publications and Citations by Year

The number of cited publications was highest for documents published in 2015 (122 citations per publication), while the lowest was for those published in 2011 (64 citations per publication). Productively, the year 2014 presented the highest h-index of 20 for authors. Additionally, Hirsch (2005) had proposed the h-index, which gives an estimate of the significance, importance, as well as researchers' cumulative research contributions' high impact. The h-index is a commonly used metric for measuring scientific performance that is now included in major bibliographic databases, for instance, Scopus and Web of Science (Van Eck & Waltman, 2017).

The second RQ of this study focuses in identifying the key topic areas based on subject areas, top keywords and co-occurrence analysis. To answer RQ2, we had analyzed the citation networks of 1056 articles according to (a) the publishing of a document by subject area, and (b) the top keywords and co-occurrence analysis. Keyword co-occurrence analysis is an effective content analysis method to map the strength of association between keywords in the literature (Shmagun et al., 2020). The released materials were then categorised according to their topic areas, as shown in Table 4.

Table 4. Subject Area

Subject Area	Total Publications (TP)	Percentage (%)
Social Sciences	960	90.91%
Chemistry	950	89.96%
Biochemistry, Genetics and Molecular Biology	22	2.08%
Chemical Engineering	18	1.70%
Pharmacology, Toxicology and Pharmaceutics	16	1.52%
Computer Science	13	1.23%
Medicine	9	0.85%
Health Professions	6	0.57%
Mathematics	6	0.57%
Dentistry	4	0.38%
Engineering	4	0.38%
Environmental Science	4	0.38%
Psychology	4	0.38%
Agricultural and Biological Sciences	3	0.28%
Materials Science	3	0.28%
Multidisciplinary	3	0.28%
Arts and Humanities	2	0.19%
Neuroscience	2	0.19%
Physics and Astronomy	2	0.19%

Overall, the distribution revealed that organic chemistry education research has evolved in a variety of topic areas. As reported, most of the documents examined are in social sciences and chemistry areas with 960 (90.91%) and 950 (89.96%) publications respectively. The subject areas of mathematics, health professions, medicine, computer science, toxicology and pharmaceutics, pharmacology, chemical engineering, biology, genetics and molecular, as well as biochemistry, each accounted for more than five documents on organic chemistry education.

To address RQ2, the study focused on identifying the keywords that are most frequently used among scholars in organic chemistry education research. The keywords from the 1056 organic chemistry education studies were summarized and presented in Table 5. The 'organic chemistry' keyword was revealed as the most intermittently used keyword in the organic chemistry education literature. The second most repeatedly used keyword is second-year undergraduate. This finding is logical since the organic chemistry subject is usually studied by second-year undergraduate students. Other common keywords that came up more than 100 times were laboratory instruction, hands-on learning/manipulative, upper-division undergraduate, inquiry-based/discovery learning, synthesis, NMR Spectroscopy, first-year undergraduate/general, green chemistry and curriculum.

In mapping the authors' keywords, the VOSviewer software at https://www.vosviewer.com, was used to visualize the bibliometric networks. The relationships of the keywords to other keywords were shown by the font size, circle size, connecting line thickness and colour. Keyword co-occurrence happens when two keywords exist in the same article, suggesting that the two concepts are related (Baker et al., 2020).

Table 5. Top Keywords

Author Keywords	Total Publications (TP)	Percentage (%)
Organic Chemistry	889	84.19%
Second-Year Undergraduate	516	48.86%
Laboratory Instruction	383	36.27%
Hands-On Learning/Manipulatives	302	28.60%
Upper-Division Undergraduate	245	23.20%
First-Year Undergraduate/General	178	16.86%
NMR Spectroscopy	176	16.67%
Synthesis	159	15.06%
Inquiry-Based/Discovery Learning	151	14.30%
Green Chemistry	112	10.61%
Curriculum	103	9.75%
Collaborative/Cooperative Learning	89	8.43%
Computer-Based Learning	85	8.05%
Problem Solving/Decision Making	83	7.86%
Student-Centered Learning	82	7.77%
Internet/Web-Based Learning	68	6.44%
Mechanisms Of Reactions	68	6.44%
High School/Introductory Chemistry	63	5.97%
IR Spectroscopy	63	5.97%
Catalysis	59	5.59%

Figure 3 depicts the author's keyword network visualisation, which demonstrates that each keyword had at least 10 occurrences. Hence, from the total number of 754 keywords, 114 met these criteria. The overall co-occurrence strength linkages having other keywords was determined for each of the 114 keywords (Van Eck & Waltman, 2008, 2017; Waltman et al., 2010). Next, these keywords were divided into seven clusters, and the size of the nodes represented the frequency of keywords. Meanwhile, the different colour of the node represented the different clusters to which it belonged (Zhang et al., 2020).

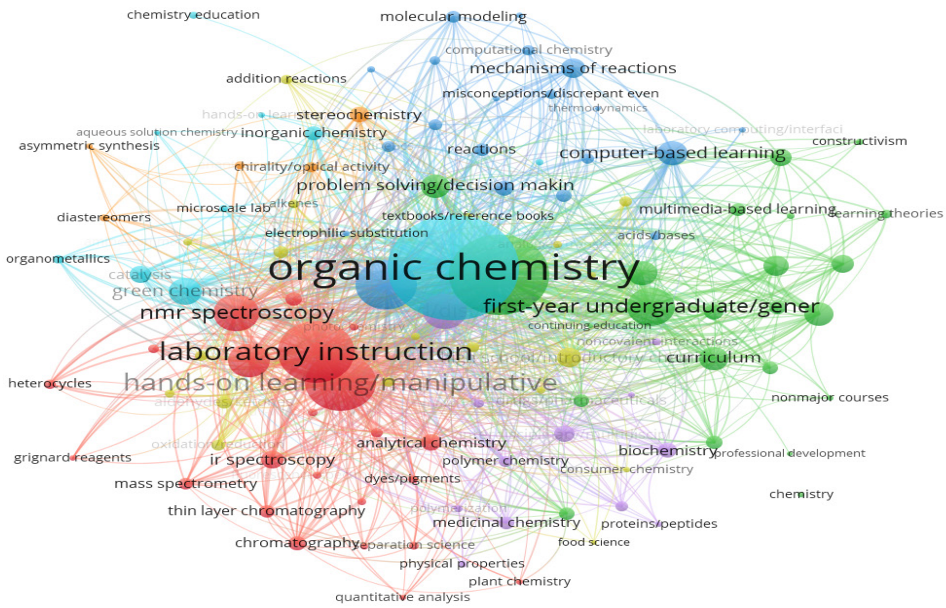

Figure 3. Author Keywords' Network Visualization Map with at least 10 Occurrences

Cluster analysis entails using a variety of algorithms to cluster natural network divisions based on similarity and reduce inter-cluster similarities (Bazm & Seyyed Mehdi Kalantar, 2016). This cluster of keywords, extracted from the title, abstract and author's keywords for each publication, belonged to a specific cluster (Van Eck & Waltman, 2017). For this study, the parameter chosen was 10 so that for every tenth publication, the basic cluster of a subject area will be formed (Nadzar et al., 2017). The first cluster (red colour) is centred around 'laboratory instruction' as the largest node size whereas the size reflected the publications number in which the term was found. Besides, the number of clusters to which the terms have been assigned represented the total number of links with other nodes so-called "total link strength" metric (Van Eck & Waltman, 2017; Shmagun et al., 2020). The 'Hands-On Learning/Manipulatives' node was the nearest to the 'laboratory instruction' node and the close distance between both keywords suggested the strong relation as well as the important connection between these two (Nadzar et al., 2017; Van Eck & Waltman, 2017). Education and Curriculum of Chemistry were located in Cluster 2 (green colour) with the top keywords comprising Second-Year Undergraduate, First-Year Undergraduate/General, Curriculum, Collaborative /Cooperative Learning, Problem Solving/Decision Making, Student-Centred Learning, and Internet/Web-Based Learning. Second-Year Undergraduate, as the highest frequency keyword, showed a strong relationship with the other Cluster 2 terms with 111 links and 3419 of the total link strengths. For Cluster 3 (blue colour), among the 22 items presented, only two top keywords about Chemistry Education appeared which were Upper-Division Undergraduate as well as Mechanisms of Reactions terms. Cluster 4 (yellow colour) keywords mostly included the functional group of organic compounds like alcohols, aldehyde, alkanes, alkenes, amides, amines and aromatic compounds. However, these keywords were not included in top keywords as written in Table 5. While for biochemistry and medicinal chemistry fields, their keywords were in Cluster 5 (purple colour). Moreover, the keyword with the highest frequency, 'organic chemistry' was presented in Cluster 6 (cyan colour) together with the other nine items. Finally, Cluster 7 (orange colour) is concerned about organic compound properties in terms of asymmetric synthesis, chirality/optical activity, diastereomers, enantiomers and stereochemistry. Apart from that, keyword analysis also provided meaningful insight into the degree of importance or popularity of a specific issue in a given research domain.

Meanwhile, this study explored the characteristics of scientific collaborations on organic chemistry education research to answer research question RQ3 by interpreting (a) the top contributors to publications by country, (b) the most influential institutions, (c) the most active journal, (d) citations analysis, and (e) the authorship analysis.

Table 6 displays the top countries whose authors had contributed to the organic chemistry education research publications. The United States (673 publications) held the leading position, followed by Canada (63 publications) and the United Kingdom (45 publications). According to national affiliations, the other's contribution by authors represented less than 30 publications which authors from Brazil, Germany, China, Portugal, France, Spain, Australia, Ireland, Singapore, Turkey, Italy, Japan, Belgium, India, Mexico, Malaysia, and The Netherlands. Apparently, organic chemistry education research plays a prominent role in a variety of geographical regions.

Table 6. Top Countries Contributed to the Publications

Country	TP	NCP	TC	C/P	C/CP	h	g
United States	673	592	8730	12.97	14.75	31	72
Canada	63	54	576	9.14	10.67	15	19
United Kingdom	45	42	285	6.33	6.79	9	14
Brazil	29	23	162	5.59	7.04	7	11
Germany	27	21	129	4.78	6.14	7	10
China	23	15	212	9.22	14.13	6	14
Portugal	17	16	164	9.65	10.25	9	12
France	15	11	98	6.53	8.91	5	9
Spain	15	14	100	6.67	7.14	7	9
Australia	13	12	81	6.23	6.75	5	8
Ireland	12	11	95	7.92	8.64	6	9
Singapore	10	10	93	9.30	9.30	6	9
Turkey	10	8	34	3.40	4.25	3	5
Italy	9	8	59	6.56	7.38	3	7
Japan	9	6	39	4.33	6.50	2	6
Belgium	7	6	30	4.29	5.00	4	5
India	7	6	72	10.29	12.00	4	7
Mexico	7	6	36	5.14	6.00	3	6
Malaysia	6	5	30	5.00	6.00	2	5
Netherlands	6	6	19	3.17	3.17	2	4
Poland	6	5	38	6.33	7.60	3	6
Russian Federation	6	4	8	1.33	2.00	2	2

Figure 4 visualized the network visualization map of academic citations by countries. The visualization map presented five clusters based on the co-occurrence of countries according to the authors' affiliations, including all countries that are involved in at least six publications. This condition is true for 22 countries.

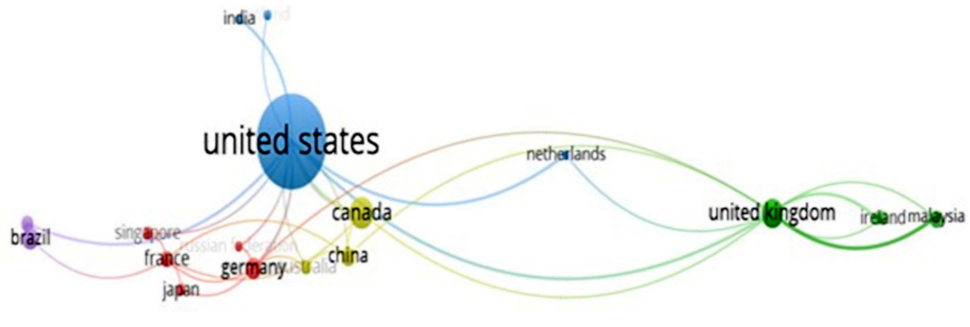

Figure 4. Network Visualization Map of the Citation based on Different Countries
Note: Minimum number of documents of an author = 5; Minimum number of citations of an author = 5

The size of a country's node represents the number of publications that are associated with the country. The first cluster (red) consists of five countries, France, Germany, Japan, Russian Federation, and Singapore. The second cluster (green) consists of five countries, including the United Kingdom, which was the third rank country, followed by Ireland, Malaysia, Turkey, and Portugal. Cluster 3 (blue) encompassed the leading country, the United States, with another three countries, which were India, The Netherlands, and Poland. The fourth cluster (yellow) consists of three countries were Canada, Australia, and China, while Cluster 5 (purple) comprises the Brazil and Spain countries.

Table 7 displays the top influential institutions on organic chemistry education research originating from each institution. Out of the 1,056 documents, the University of Toronto (19 publications) contributed most to publications on organic chemistry education. This was followed by Miami University, University of Michigan, Ann Arbor, Purdue University, University of Ottawa, and Michigan State University, with 17, 16, 14, 13, and 12 total publications, respectively. Three institutions shared the same number of 11 publications; the institutions are College of Saint Benedict Saint John's University, NC State University, and the University of Wisconsin-Madison. The others only contributed ten and below the number of publications.

Table 7. Top Influential Institutions

Affiliation	Country	TP	NCP	TC	C/P	C/CP	h	g
University of Toronto	Canada	19	19	164	8.63	8.63	9	12
Miami University	United States	17	16	475	27.94	29.69	10	17
University of Michigan, Ann Arbor	United States	16	15	114	7.13	7.60	6	10
Purdue University	United States	14	14	235	16.79	16.79	7	14
University of Ottawa	Canada	13	12	215	16.54	17.92	9	13
Michigan State University	United States	12	12	201	16.75	16.75	7	12
College of Saint Benedict Saint John's University	United States	11	11	94	8.55	8.55	7	9
NC State University	United States	11	10	107	9.73	10.70	5	10
University of Wisconsin-Madison	United States	11	10	137	12.45	13.70	5	11
University of South Florida, Tampa	United States	10	8	72	7.20	9.00	5	8
University of Cincinnati	United States	10	7	51	5.10	7.29	4	7
University of Georgia	United States	10	9	84	8.40	9.33	6	9
Iowa State University	United States	9	9	149	16.56	16.56	6	9
University of California, Irvine	United States	9	5	41	4.56	8.20	3	6
University of California, Davis	United States	9	9	112	12.44	12.44	5	9
Justus Liebig University Giessen	Germany	9	8	54	6.00	6.75	4	7
National University of Singapore	Singapore	9	9	91	10.11	10.11	6	9
University of California, Santa Barbara	United States	9	9	174	19.33	19.33	7	9

Table 8 lists the most active journals on organic chemistry education research. The Journal of Chemical Education ranked first with 879 publications, followed by the Chemistry Education Research and Practice at second place (16 publications). While for both the Biochemistry and Molecular Biology Education and the Educacion Quimica journals, only ten publications were listed. The Journal of Research In Science Teaching is leading in CiteScore (CS) even though the journal was not listed in the top five institutions with the highest publications. Scopus has introduced CS as a new scientometric indicator (citation impact metric) for tracking journals' performance in terms of citation analysis. The database of Elsevier had several scientific quality assessment metrics such as Scimago Journal Rank and (SJR) Source Normalized Impact per Paper (SNIP) indicators (Zijlstra & McCullough, 2016). Consequently, CS can provide a more unique features of citations compared to the Impact Factor (Okagbue et al., 2019).

Table 8. Most Active Journals

Source Title	TP	TC	Publisher	Cite Score	SJR 2019	SNIP 2019
Journal Of Chemical Education	879	7426	American Chemical Society	3.4	0.473	1.374
Chemistry Education Research and Practice	16	103	Royal Society of Chemistry	3.9	0.766	1.577
Biochemistry And Molecular Biology Education	10	49	Wiley-Blackwell	1.8	0.458	0.826
Educacion Quimica	10	32	National Autonomous University of Mexico, Faculty of Chemistry	1.0	0.168	0.424
Quimica Nova	8	13	Sociedade Brasileira de Quimica	1.1	0.199	0.396
Journal Of Research in Science Teaching	6	209	Wiley-Blackwell	7.2	3.012	3.231
International Journal of Science Education	5	125	Taylor & Francis	2.8	1.058	1.626
Currents In Pharmacy Teaching and Learning	4	5	Elsevier	1.2	0.358	0.726
Journal Of Dental Education	4	11	American Dental Education Association	2.1	0.437	0.885
Journal Of The Korean Chemical Society	4	10	Korean Chemical Society	0.5	0.173	0.251
Actualite Chimique	3	1	Societe Francaise de Chimie	0.2	0.147	0.067
Yakugaku Zasshi	3	2	Pharmaceutical Society of Japan	0.5	0.155	0.21

Citation analysis is a tool for determining the impact and quality of research papers in a systematic manner as this analysis is easy to compute (Aristodemou & Tietze, 2018; Hou et al., 2018). Table 9 reports the citation metric of the papers obtained from the Scopus database. A total of 11102 citations were recorded in the ten years between 2011 to 2020 for 1056 articles, with an average of 1110 citations per year and ten citations per paper.

Table 9. Citations Metrics

Metrics	Data
Publication years	2011-2020
Citation years	10 (2011-2021)
Papers	1056
Citations	11102
Citations/year	1110.20
Citations/paper	10.51
Citations/author	4072.99
Papers/author	475.66
h-index	34
g-index	74

The top 20 articles in the field with the most citations of organic chemistry education are shown in Table 10.

Table 10. Top 20 Highly Cited Articles on Organic Chemistry Education

No.	Authors	Title	Year	Cites	Cites per Year
1	Hanwell et al. (2012)	Avogadro: An advanced semantic chemical editor, visualization, and analysis platform	2012	2683	298.11
2	Ma et al. (2016)	Fluorescence Aggregation-Caused Quenching versus Aggregation-Induced Emission: A Visual Teaching Technology for Undergraduate Chemistry Students	2016	151	30.2
3	Cooper et al. (2013)	An investigation of college chemistry students' understanding of structure-property relationships	2013	84	10.5
4	Grove et al. (2012b)	Decorating with arrows: Toward the development of representational competence in organic chemistry	2012	70	7.78
5	Christiansen (2014)	Inverted teaching: Applying a new pedagogy to a university organic chemistry class	2014	66	9.43
6	Bretz et al. (2013)	What faculty interviews reveal about meaningful learning in the undergraduate chemistry laboratory	2013	64	8
7	McClary and Bretz (2012)	Development and assessment of a diagnostic tool to identify organic chemistry students' alternative conceptions related to acid strength	2012	62	6.89
8	Hein (2012)	Positive impacts using POGIL in organic chemistry	2012	62	6.89
9	Chase et al. (2013)	Implementing process-oriented, guided-inquiry learning for the first time: Adaptations and short-term impacts on students' attitude and performance	2013	60	7.5
10	Galloway and Bretz (2015)	Development of an Assessment Tool to Measure Students' Meaningful Learning in the Undergraduate Chemistry Laboratory	2015	58	9.67
11	Grove, et al. (2012a)	Does mechanistic thinking improve student success in organic chemistry?	2012	57	6.33
12	Hill et al. (2013)	Aerobic alcohol oxidation using a copper(I)/TEMPO catalyst system: A green, catalytic oxidation reaction for the undergraduate organic chemistry laboratory	2013	54	6.75
13	Mooring et al. (2016)	Evaluation of a Flipped, Large-Enrollment Organic Chemistry Course on Student Attitude and Achievement	2016	50	10
14	Raker et al. (2013)	The ACS exams institute undergraduate chemistry anchoring concepts content map II: organic chemistry	2013	49	6.13
15	McClary and Talanquer (2011)	College chemistry students' mental models of acids and acid strength	2011	49	4.9
16	Che (2013)	Nobel Prize in chemistry 1912 to Sabatier: organic chemistry or catalysis?	2013	47	5.88
17	Gupta et al. (2014)	Assigning oxidation states to organic compounds via predictions from X-ray photoelectron spectroscopy: A discussion of approaches and recommended improvements	2014	45	6.43
18	Flynn and Biggs (2012)	The development and implementation of a problem-based learning format in a fourth-year undergraduate synthetic organic and medicinal chemistry laboratory course	2012	45	5
19	Galloway et al. (2016)	Investigating Affective Experiences in the Undergraduate Chemistry Laboratory: Students' Perceptions of Control and Responsibility	2016	44	8.8
20	Flynn and Ogilvie (2015)	Mechanisms before reactions: A mechanistic approach to the organic chemistry curriculum based on patterns of electron flow	2015	44	7.33

The article that achieved the highest citation entitled, "Avogadro: An advanced semantic chemical editor, visualization, and analysis platform", was published in the Journal of Cheminformatics in 2012. There were 2683 citations related to this article, with 298.1 citations per year. Therefore, Hanwell et al. (2012) has been known the most prolific author who received the highest citation for organic chemistry education articles.

In presenting the network visualization (Figure 5 and Figure 7), the VOSviewer software was used to map the co-citation as well as co-authorship among different authors. The mapping utilised the full counting method. For the unit analysis of cited authors, a minimum of 15 citations of an author were chosen for co-citation analysis. The nodes' patterns varied according to the thickness of the lines, circle size, font size and colour. The number of times a document has been mentioned is related to its size; therefore, the larger the node, the greater the citation "total link strength" and count (MacDonald & Dressler, 2018). The nodes that are close to each other indicated a more closely linked article content. The authors' co-citation analysis resulted in the establishment of six clusters, each represented by a distinct hue. The co-citation trend of 391 authors referenced at least 15 times by studies' sample is shown in Figure 5. The writers are grouped together based on how similar their co-citation patterns are. Dicks, A.P., Bretzs, S.L., Raker, J. R., Flynn, A. B., Corey, E. J., and Bissember, A. C. are the authors with highest co-citation in red (Cluster 1), green (Cluster 2), blue (Cluster 3), yellow (Cluster 4), purple (Cluster 5) and turquoise (Cluster 6) colour, respectively. However, the node size indicated that the most influential authors within the organic chemistry education literature were Cooper, M. M.

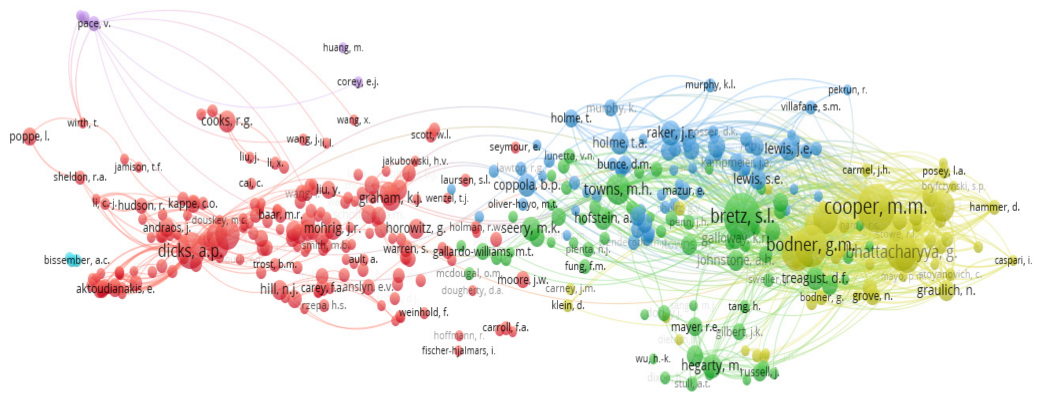

Figure 5. The Co-citation Network Visualization Map
Notes: Unit of analysis = cited authors; Counting method: Full counting; Minimum number of citations of an author = 15

Co-citation analysis is basically employing co-citation counts to construct similarity measures between documents, authors, or journals. Hence the more instances of the two authors cited together, the more likely their content is interrelated (Zupic & Čater, 2015; Hallinger, 2019). Note that the idea of author co-citation can be clarified by referring to Figure 6, which has adopted two articles authored by Cooper et al. (2016) and Bretz & McClary (2015). Both were shown in the three other articles' references, Crandell et al. (2018), Webber & Flynn (2018), and Farhat et al. (2019). Hence, those two articles were called 'cited documents' while the other three articles were 'citing documents', which are linked to the two documents cited. The links show a relationship to indicate the similarities among documents (Hallinger, 2019).

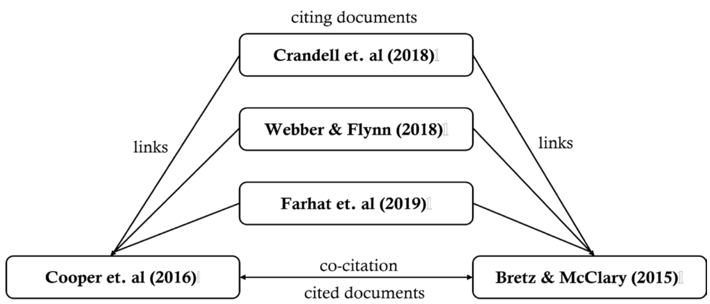

Figure 6. Example of Co-citation and Links

There is a total of 24 authors who have contributed to a total of 1056 publications on organic chemistry education. Table 11 shows the authors' number per document. From the 1056 publications considered in this study, 200 documents (18.94%) were single-authored publications, while the remaining had more than one author. Most of the articles on organic chemistry education were co-authored by two (24.24%), followed by three authors (19.98%) and four authors (15.34%). Only two documents with more than 13 writers were co-authored.

Table 11. Number of Author(s) per Document

Author Count	Total Publications (TP)	Percentage (%)
0*	2	0.19%
1	200	18.94%
2	256	24.24%
3	211	19.98%
4	162	15.34%
5	89	8.43%
6	51	4.83%
7	35	3.31%
8	16	1.52%
9	13	1.23%
10	12	1.14%
11	2	0.19%
12	5	0.47%
13	2	0.19%
Total	1056	100.00%

*Conference review document. No author is listed.

Co-authorship maps are applied when two or more authors collaborate with each other to write a paper and these collaboration patterns reveal the structure of scientific networks (Zupic & Čater, 2015; Xu & Chang, 2020). Figure 7 presented the co-authorship network map with a minimum of two documents and two citations per author are required. Thus, 339 authors out of a total of 2814 met the thresholds and remained in the analysis. Note that the co-authorship map of authors included seven clusters in different colours.

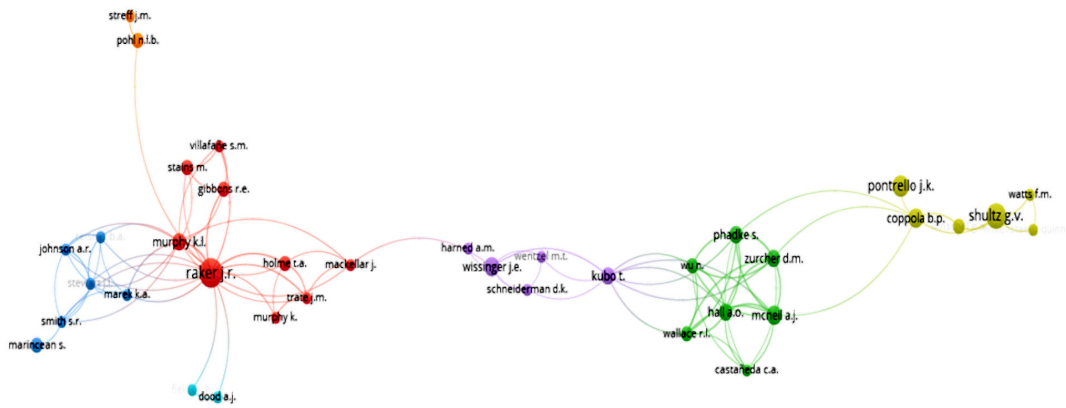

Figure 7. Network Visualization Map of the Co-authorship
Note: Unit of analysis = Authors; Counting method: Full counting; Minimum number of documents of an author = 2; Minimum number of citations of an author = 2

Based on Figure 7, the colour of red, green, blue, yellow, purple, turquoise and orange are depicted of Cluster 1, Cluster 2, Cluster 3, Cluster 4, Cluster 5, Cluster 6 and Cluster 7 respectively. The patterns vary according to the colour, font size, circle size, as well as thickness of the lines. The connecting lines patterns indicate the relationship strength among authors (Wahid et al., 2020). Raker J. R., who was the largest node which represented him as the most active author with the highest degree of collaborations as well as highest total publications among 339 visible co-authors.

CONCLUSION

From 2011 to 2020, bibliometric analysis was implemented to undertake publications' review associated with organic chemistry education. Also, the Scopus database was used to retrieve the bibliometric characteristics of 1056 publications. In response to the RQ1 according to the publication trend in organic chemistry education, English was found as the major language. The results indicate that the publication of journals on this topic has continuously grown and been widely published. However, total citations of articles per year have decreased from 2016 until 2020. The second RQ seeks to ascertain the key topic areas which had been discussed in this analysis. It concluded that the main subject areas were social sciences and chemistry with 90.91% and 89.96% responses respectively. The keywords that were most frequently used among scholars in organic chemistry education research was identified as the 'organic chemistry' word which contributed 87.19% of the total keywords often listed in organic chemistry education research. The keywords co-occurrence network revealed that the focus of research trends in organic chemistry education has shifted from laboratory equipment investigation to multimedia-based teaching methods to develop scientific reasoning abilities about reactions in organic chemistry, as many of these previous studies discuss student difficulties and misconceptions in understanding organic chemistry.

Meanwhile, in answering RQ3 of this study, the analysis recorded the major contributors by (a) countries; (b) institution; (c) journal; (d) citation analysis; and (e) authorship analysis in organic chemistry education research and explained how these contributors collaborated. The VOSviewer software that had been used in this study was able to map the citation and co-authorship network by exploring the characteristics of scientific collaboration on organic chemistry education research. Implementing Harzing's Publish or Perish software, the citation metrics summarized that there were 11102 citations reported within ten years (2011–2020) for 1056 articles, with an average of 1110 citations per year as well as ten citations per paper. The conclusion with reference to RQ3 are enumerated below: (1) the United States was the center of network in organic chemistry education, which collaborated with many countries such as Canada, China, Australia, Germany, Netherlands, United Kingdom, Russian Federation, Spain, Singapore, Serbia, Poland and India. Through scientific collaboration within countries, transferable knowledge and technology from one country to another are developed, which is highly important for educational development, especially for the organic chemistry new curriculum; (2) the leading institution in the organic chemistry education field was the University of Toronto, Canada, followed by Miami University, the United States, with a total of 19 and 17 publications, respectively. Moreover, a collaboration between institutions domestically results in higher citation rates from Purdue University, which connects with Miami University and serves as the leading institution for higher total citations in the organic chemistry education area; (3) the Journal of Chemical Education (JCE) was the most active journal in the preceding 10 years. JCE is published by Division of Chemical Education, Inc. American Chemical Society, Inc. Since 1924, the JCE has been the world's leading publication for chemical education, encouraging chemistry instructors to submit their most recent findings including the new ideas in teaching methodologies; (4) furthermore, Hanwell et al. (2012) had been listed as the most productive author who received the highest citation of organic chemistry education articles, especially for his article entitled "Avogadro: An advanced semantic chemical editor, visualization, and analysis platform". However, the visualization mapping had shown that the most influential authors within organic chemistry education literature were Cooper, M. M., followed by Bretz, S.L., with the total link strength performed at 12711 and 9967, respectively. This result left a clue to figure out how their research developed over time as some of Cooper's recent publications provided good comprehensive ways in transforming the organic chemistry curriculum; (5) finally, for co-authorship analysis, Raker J. R. was acknowledged as the most active author with the highest degree of collaboration with the other authors.

To acknowledge the quality and added value of a study, its limitations should be clearly stated. First, this study relied wholly on the Scopus database and the choice of keywords used in journal titles, abstracts, and authors' keywords. Other rich databases such as Google Scholar or Web of Science documents discussing organic chemistry education were not employed in this research. Secondly, we examined only a sample of the relevant literature, which used limited search terms due to the broader area of the organic chemistry concepts. Otherwise, the period covered was fixed. Thirdly, the mapping of the co-authorship network has not been triangulated with other methods. Finally, citation analysis weaknesses also provide inherent unknown reasons for citing a certain document and self-citations. Thus, the following suggestion for future studies may be recommended: (1) Employ other analysis and counting methods such as bibliographic coupling and fractional counting to triangulate the findings, (2) Replicate the study with the use of any other databases like Web of Science to show a higher representation of publications, and (3) Explore more studies and assist in bridging the educational gap that may exist in the growth of organic chemistry education. This will make achieving educational goals easier across the world among organic chemistry educators. Despite these limitations, this study reveals some interesting insights into current organic chemistry education research and publication trends. In addition, each indicator aims to enhance research in this area, which might provide further information about how the organic chemistry curriculum will be reshaped in the future yet underpins the development of a highly-skilled STEM workforce.

REFERENCES

Ahmi, A., & Mohamad, R. (2019). Bibliometric analysis of global scientific literature on web accessibility. *International Journal of Recent Technology and Engineering*, *7*(6), 250–258.

Ahmi, A., & Mohd Nasir, M. H. (2019). Examining the trend of the research on extensible business reporting language (XBRL): A bibliometric review. *International journal of innovation, creativity and change*, *5*(2), 1145-1167.

Aristodemou, L., & Tietze, F. (2018). Citations as a measure of technological impact: A review of forward citation-based measures. *World Patent Information*, *53*(April 2017), 39–44.

Baker, H.K., Pandey, N., Kumar, S., & Haldar, A. (2020). A bibliometric analysis of board diversity: Current status, development, and future research directions. *Journal of Business Research*, *108*(August 2019), 232–246.

Bazm, S., & Seyyed Mehdi Kalantar. (2016). Bonniers kalorikompass. *International Journal Reprod BioMed*, *14*(6), 371–382.

Bodé, N. E., Deng, J. M., & Flynn, A. B. (2019). Getting past the rules and to the WHY: Causal mechanistic arguments when judging the plausibility of organic reaction mechanisms. *Journal of Chemical Education*, *96*(6), 1068-1082.

Bretz, S. L., Fay, M., Bruck, L. B., & Towns, M. H. (2013). What faculty interviews reveal about meaningful learning in the undergraduate chemistry laboratory. *Journal of Chemical Education, 90(3), 281-288.*

Bretz, S. L., & McClary, L. (2015). Students' understandings of acid strength: How meaningful is reliability when measuring alternative conceptions? *Journal of Chemical Education*, *92*(2), 212–219.

Chaloner, P. (2015). *Organic Chemistry A Mechanistic Approach*. CRC Press.

Chase, A., Pakhira, D., & Stains, M. (2013). Implementing process-oriented, guided-inquiry learning for the first time: Adaptations and short-term impacts on students' attitude and performance. *Journal of Chemical Education, 90(4), 409-416.*

Che, M. (2013). Nobel Prize in chemistry 1912 to Sabatier: Organic chemistry or catalysis? *Catalysis Today*, *218–219*(April), 162–171.

Christiansen, M. A. (2014). Inverted teaching: Applying a new pedagogy to a university organic chemistry class. *Journal of Chemical Education, 91(11), 1845-1850.*

Cooper, M. M., Corley, L. M., & Underwood, S. M. (2013). An investigation of college chemistry students' understanding of structure-property relationships. *Journal of Research in Science Teaching*, *50*(6), 699-721.

Cooper, M. M., Kouyoumdjian, H., & Underwood, S. M. (2016). Investigating Students' Reasoning about Acid-Base Reactions. *Journal of Chemical Education*, *93*(10), 1703–1712.

Cooper, M. M., Stowe, R. L., Crandell, O. M., & Klymkowsky, M. W. (2019). Organic chemistry, life, the universe and everything (OCLUE): A transformed organic chemistry curriculum. *Journal of Chemical Education*, *96*(9), 1858-1872.

Crandell, O. M., Kouyoumdjian, H., Underwood, S. M., & Cooper, M. M. (2018). Reasoning about reactions in organic chemistry: starting it in general chemistry. *Journal of Chemical Education*, *96*(2), 213-226.

DeCocq, V., & Bhattacharyya, G. (2019). TMI (Too much information)! Effects of given information on organic chemistry students' approaches to solving mechanism tasks. *Chemistry Education Research and Practice*, *20*(1), 213–228.

de Oliveira, O. J., da Silva, F. F., Juliani, F., Barbosa, L. C. F. M., & Nunhes, T. V. (2019). Bibliometric Method for Mapping the State-of-the-Art and Identifying Research Gaps and Trends in Literature: An Essential Instrument to Support the Development of Scientific Projects. In Scientometrics Recent Advances (Issue tourism, p. 13). IntechOpen. https://www.intechopen.com/books/advanced-biometric-technologies/liveness-detection-in-biometrics

Evdokimenkova, Y. B., & Soboleva, N. O. (2020). Organic chemistry in Russia: Bibliometric publication flow analysis over the past 30 years. *COLLNET Journal of Scientometrics and Information Management*, *14*(1), 23–36.

Farhat, N. J., Stanford, C., & Ruder, S. M. (2019).

Assessment of Student Performance on Core Concepts in Organic Chemistry. *Journal of Chemical Education*, *96*(5), 865–872.

Flynn, A. B., & Biggs, R. (2012). The development and implementation of a problem-based learning format in a fourth-year undergraduate synthetic organic and medicinal chemistry laboratory course. *Journal of Chemical Education*, *89*(1), 52-57.

Flynn, A. B., & Ogilvie, W. W. (2015). Mechanisms before reactions: A mechanistic approach to the organic chemistry curriculum based on patterns of electron flow. *Journal of Chemical Education*, *92*(5), 803–810.

Galloway, K. R., & Bretz, S. L. (2015). Development of an Assessment Tool to Measure Students' Meaningful Learning in the Undergraduate Chemistry Laboratory. *Journal of Chemical Education*, *92*(7), 1149–1158.

Galloway, K. R., Malakpa, Z., & Bretz, S. L. (2016). Investigating affective experiences in the undergraduate chemistry laboratory: Students' perceptions of control and responsibility. *Journal of Chemical Education*, *93*(2), 227-238.

Galloway, K. R., Stoyanovich, C., & Flynn, A. B. (2017). Students' interpretations of mechanistic language in organic chemistry before learning reactions. *Chemistry Education Research and Practice, 18*(2), 353–374.

Garg, K. C., & Pooja Kumari. (2018). PhD Theses Accepted By Aligarh Muslim University (AMU) In The Discipline Of Chemistry : A Bibliometric Study (1935-2014). *Journal Of Indian Library Association*, *54*(2).

Grove, N. P., Cooper, M. M., & Cox, E. L. (2012a). Does mechanistic thinking improve student success in organic chemistry?. *Journal of Chemical Education*, *89*(7), 850-853.

Grove, N. P., Cooper, M. M., & Rush, K. M. (2012b). Decorating with arrows: Toward the development of representational competence in organic chemistry. *Journal of Chemical Education*, *89*(7), 844–849.

Gupta, V., Ganegoda, H., Engelhard, M. H., Terry, J., & Linford, M. R. (2014). Assigning oxidation states to organic compounds via predictions from X-ray photoelectron spectroscopy: a discussion of approaches and recommended improvements. *Journal of Chemical Education*, *91*(2), 232-238.

Hallinger, P. (2019). Science mapping the knowledge base on educational leadership and management in Africa, 1960–2018. *School Leadership and Management*, *39*(5), 537–560.

Hallinger, P., & Kovačević, J. (2019). A Bibliometric Review of Research on Educational Administration: Science Mapping the Literature, 1960 to 2018. *Review of Educational Research*, *89*(3), 335–369.

Hanwell, M. D., Curtis, D. E., Lonie, D. C., Vandermeersch, T., Zurek, E., & Hutchison, G. R. (2012). Avogadro: an advanced semantic chemical editor, visualization, and analysis platform. *Journal of cheminformatics*, *4*(1), 1-17.

Hein, S. M. (2012). Positive impacts using POGIL in organic chemistry. *Journal of Chemical Education*, *89*(7), 860-864.

Hill, N. J., Hoover, J. M., & Stahl, S. S. (2013). Aerobic alcohol oxidation using a copper(I)/TEMPO catalyst system: A green, catalytic oxidation reaction for the undergraduate organic chemistry laboratory. *Journal of Chemical Education*, *90*(1), 102–105.

Hou, J., Yang, X., & Chen, C. (2018). Emerging trends and new developments in information science: a document co-citation analysis (2009–2016). *Scientometrics*, *115*(2), 869–892.

Lathwesen, C., & Belova, N. (2021). Escape rooms in stem teaching and learning—prospective field or declining trend? A literature review. *Education Sciences*, *11*(6).

Ma, X., Sun, R., Cheng, J., Liu, J., Gou, F., Xiang, H., & Zhou, X. (2016). Fluorescence aggregation-caused quenching versus aggregation-induced emission: a visual teaching technology for undergraduate chemistry students. *Journal of Chemical Education*, *93*(2), 345-350.

MacDonald, K. I., & Dressler, V. (2018). Using Citation Analysis to Identify Research Fronts: A Case Study with the Internet of Things. *Science and Technology Libraries*, *37*(2), 171–186.

Mazzuco, A., Krassmann, A. L., Reategui, E., & Gomes, R. S. (2022). A systematic review of augmented reality in chemistry education. *Review of Education*, *10*(1).

McClary, L. M., & Bretz, S. L. (2012). Development and assessment of a diagnostic tool to identify organic chemistry students' alternative conceptions related to acid strength. *International Journal of Science Education*, *34*(15), 2317-2341.

McClary, L., & Talanquer, V. (2011). College chemistry students' mental models of acids and acid strength. *Journal of Research in Science Teaching*, *48*(4), 396-413.

Mooring, S. R., Mitchell, C. E., & Burrows, N. L. (2016). Evaluation of a flipped, large-enrollment organic chemistry course on student attitude and achievement. *Journal of Chemical Education*, *93*(12), 1972-1983.

Morrison, R. T., & Boyd, R. N. (1959). *Organic Chemistry*. Allyn and Bacon.

Nugraheni, A. R. E., Adita, A., & Srisawasdi, N. (2020). Blended learning supported chemistry course: A systematic review from 2010 to 2019. *ICCE 2020 - 28th International Conference on Computers in Education, Proceedings*, *2*, 444–450.

Nadzar, N. M. A. M., Bakri, A., & Ibrahim, R. (2017). A bibliometric mapping of malaysian publication using co-word analysis. *Int. J. Adv. Soft Comput. Appl*, *9*(3), 90-113.

O 'Dwyer, A., & Childs, P. E. (2017). Who says Organic Chemistry is Difficult ? Exploring Perspectives and Perceptions. *Eurasia Journal of Mathematics, Science and Technology Education*, *13*(7), 3599-3620.

Okagbue, H. I., Bishop, S. A., Oguntunde, P. E., Adamu, P. I., Opanuga, A. A., & Akhmetshin, E. M. (2019). Modified CiteScore metric for reducing the effect of self-citations. *Telkomnika (Telecommunication Computing Electronics and Control)*, *17*(6), 3044–3049.

Okuyama, T., & Maskill, H. (2013). *Organic Chemistry: A Mechanistic Approach*. OXFORD University Press.

Raker, J., Holme, T., & Murphy, K. (2013). The ACS Exams Institute undergraduate chemistry anchoring concepts content map II: Organic Chemistry. *Journal of Chemical Education*, *90*(11), 1443-1445.

Shmagun, H., Oppenheim, C., Shim, J., & Kim, J. (2020). The Uptake of Open Science: Mapping the Results of a Systematic Literature Review. *ITM Web of Conferences*, *33*, 01001.

Smith, M. B. (2020). *A Q&A Approach To Organic Chemistry*. Taylor & Francis Group.

Tang, K. Y., Chang, C. Y., & Hwang, G. J. (2021). Trends in artificial intelligence-supported e-learning: a systematic review and co-citation network analysis (1998–2019). *Interactive Learning Environments*, *0*(0), 1–19.

Tomaszewski, R. (2020). Application of Bibliometric Analysis to Letters Journals in Organic Chemistry. *Serials Librarian*, *79*(1–2), 91–106.

Van Eck, N. J., & Waltman, L. (2017). Citation-based clustering of publications using CitNetExplorer and VOSviewer. *ArXiv*, 1–25.

Verrall, B., & Pickering, C. M. (2020). Alpine vegetation in the context of climate change: A global review of past research and future directions. *Science of the Total Environment*, 748, 141344.

Wahid, R., Ahmi, A., & Alam, A. S. A. F. (2020). Growth and Collaboration in Massive Open Online Courses: A Bibliometric Analysis. *International Review of Research in Open and Distance Learning*, *21*(4), 292–322.

Webber, D. M., & Flynn, A. B. (2018). How Are Students Solving Familiar and Unfamiliar Organic Chemistry Mechanism Questions in a New Curriculum? *Journal of Chemical Education*, *95*(9), 1451–1467.

Xu, Q. A., & Chang, V. (2020). Co-authorship network and the correlation with academic performance. *Internet of Things*, *12*, 100307.

Zakaria, R., Ahmi, A., Ahmad, A. H., & Othman, Z. (2021). Worldwide melatonin research: a bibliometric analysis of the published literature between 2015 and 2019. *Chronobiology International*, *38*(1), 27–37.

Zijlstra, H., & McCullough, R. (2016). *CiteScore: a new metric to help you track journal performance and make decisions.* Elsevier.

Zupic, I., & Čater, T. (2015). Bibliometric Methods in Management and Organization. *Organizational Research Methods*, *18*(3), 429–472.