ORIGINAL ARTICLE

Trends and Issues in Science Education in the New Millennium: A Bibliometric Analysis of the JRST

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Abstract: *As a real time socio-scientific issue, the COVID-19 pandemic has clearly shown us the need for the public to understand science. As experts have repeatedly stressed in recent years, science education plays an important role in developing scientifically literate societies. In this context, it is critical to consider which subjects science educators frequently concentrate on and the messages they give to researchers, policymakers, and other stakeholders. Therefore, the purpose of this study was to use bibliometric data to understand the topics that the articles in the Journal of Research in Science Teaching (JRST), one of the flagship journals about science education and teaching, focused on over the last 20 years. This study employed both descriptive and bibliometric analysis. Based on data from the Web of Science (WoS), descriptive analyses are presented as frequencies and percentages and we used VOSviewer software for bibliometric analysis. Findings showed that more than 80% of the authors of the JRST are from the United States, Australia, Canada, and the United Kingdom. Moreover, results of these analyses demonstrate that the researchers publishing in the JRST focused on two main ideas over the past 20 years: "Which science teaching methods and strategies are most effective?" and "What can be done to make science teaching more inclusive?" As a result, it can be clearly seen that JRST has special attention on inclusive approach in science education which should be designed to include traditionally underrepresented groups.*

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Introduction

CULTIVATING a scientifically literate society is critical to making sense of and producing solutions to many of the most pressing issues facing the world today. As a real time socio-scientific issue, the COVID-19 pandemic has clearly demonstrated the need for the public to understand science (Reiss, 2020). It is not only pandemics that necessitate this type of widespread scientific literacy, but also wars, unequal distributions of global resources, environmental problems, and socio-cultural disparities, and civil rights. Individual nations and international organizations develop policies to address these issues based on scientific studies conducted by experts. As experts have repeatedly stressed in recent years, science education plays an important role in developing scientifically literate societies (Bybee, 1997; Roberts & Bybee, 2014; Roth & Barton, 2004). In this context, it is critical to consider which subjects science educators frequently concentrate on and the messages they give to researchers, policymakers, and other stakeholders. Therefore, synthesizing previous studies will help us advance this line of research (Zupic & Cater, 2015). Similarly, if we understand the history of science education, we can understand our current shortcomings and make more reliable predictions about the future (Yager, 2000). As a result, the present study aimed to use bibliometric data to understand the topics of the articles published in the *Journal of Research in Science Teaching* (JRST), one of the flagship journals about science education, over the last 20 years. Thus, we generated the following research questions:

1. *What are the descriptive characteristics of the studies published in JRST over the past 20 years?*
2. *What does the intellectual structure of the past 20 years of JRST publications look like?*

Why JRST?

The current body of knowledge in a particular field is the result of years of scientific communication between communities of researchers (Assefa & Rorissa, 2013). In this context, the output of scientific communication consists of journal articles, books, and conference papers. Using bibliometric techniques to analyze the knowledge structure and scientific characteristics of a particular journal's publications can provide a guide for the journal's authors, as well forecast the journal's future development. In addition, it can reveal the current status and development trends of a journal, providing the opportunity to evaluate its contribution to the field (Xu et al., 2018). Such studies can take place on a small scale, for example for an internal evaluation of a journal, or at a high level, such as shaping the science policy of an entire country (Al et al., 2010). For this study, we focused our attention on reviewing the Journal of Research in Science Teaching (JRST). The JRST is the official journal of the National Association for Research in Science (NARST), a global consortium dedicated to improving science education through research. As one of the most important science education journals included in the Social Sciences Citation Index, this journal was a natural choice for this research, since it has a strong influence on the field globally and provides important insight into current trends in science education publications. According to Journal Citation Reports data, the JRST ranked 49th among 263 “education & educational research” journals in 2022, with an impact factor of 3.918.

Theoretical Background: What does Bibliometric Analysis do?

The goal of research synthesis is to place individual studies in conversation with each other, to put their findings into perspective (Leary & Walker, 2018). Due to the rapid increase of research in science education in recent years, it is important to examine this large amount of existing educational research data from a bird’s eye view to develop future studies and policies (Authors, 2021). With such a wealth of research, it is becoming increasingly difficult for scholars to keep up with the relevant literature in their field. Therefore, researchers should employ various methods to cope with the richness of this data, filter important studies by predicting their real effects, and produce meaningful results by discovering the structure underlying the field. Several different field review approaches can be used depending on the review’s goals, as well as the amount and nature of the literature to under analysis (Donthu et al., 2021); the most popular of these methodologies include meta-analysis, meta-synthesis, and bibliometry. Meta-synthesis is a method from the qualitative paradigm (Leary & Walker, 2018). Meta-analysis, which works quantitatively, reveals relationships that are not examined in researched studies by using empirical evidence (Donthu et al., 2021). On the other hand, bibliometric studies summarize large volumes of bibliometric data (such as keywords and citations) to present the intellectual structure and emerging trends of a research topic or field (Donthu et al., 2021; Güneş et al., 2017; Pritchard, 1969; Zupic & Cater, 2015).

Bibliometry involves statistical analysis of written publications, such as books, articles or conference papers (Pritchard, 1969). This area of research began when Hulme coined the term “statistical bibliography” in 1922 (Pritchard, 1969). Later, Pritchard (1969) drew attention to the importance of the concept and proposed a new term, stating that “...it is to be hoped…this term BIBLIOMETRICS will be used explicitly in all studies which seek to quantify the processes of written communication and will quickly gain acceptance" (p. 2). Bibliometry then attracted the attention of researchers from diverse scientific fields, who applied it to their own areas of study (Merigo & Yang, 2017). Used for decades to evaluate the research performance of individuals, teams, and academic units in various scientific fields, this method offers the potential to recognize interdisciplinary collaboration, investigate the structure of scientific fields, and document the impact of science and technology (e.g., publications and patents) research on scientific progress (Anninos, 2014; Moed, 2005; Narin, 1976).

Traditionally, bibliometric approaches are used to determine the scientific and academic value of a particular journal, identify the key scholars and documents in a research field (through co-authorship, citation, or co-citation), and create thematic maps to identify popular and emerging topics, collaboration patterns, and interdisciplinary models through co-word or co-occurrence analysis (Anninos, 2014; Assefa & Rorissa, 2013; Callon et al., 1986; Hallinger & Kovačević, 2019; Laengle et al., 2018). Bibliometry can also quantify the timeliness of a discipline's content (Al et al., 2010). Moreover, bibliometric methods provide a useful tool in literature reviews before reading even begins, by guiding the researcher to the most influential studies and mapping the research area without subjective bias (Zupic & Cater, 2015).

Analyzing the publications of a specific journal can yield several benefits. Peer-reviewed academic journals are seen as the most reliable sources of knowledge in the scientific community (Gholampour et al., 2019). These journals present new developments in a field to the scientific community through an objective review process, and the citations that these studies receive spread this information and increase its reliability (Westbrook, 1960). As a result, analyzing the content and citations of studies published in peer-reviewed journals provides us with information about what is credible and widely accepted in each field. Furthermore, by reviewing particularly prominent journals, researchers can make data-based assertions to editors, authors, and readers on to advance and diversify the field through prioritizing particular articles and themes.

Donthu et al. (2021) grouped the main techniques of bibliometric analysis into two categories: *performance analysis and science mapping*. Publication- and citation-related metrics are used in performance analysis, which offers clues about trends in the field. On the other hand, citation, co-citation, co-authorship, and co-occurrence (co-word) analysis are typical of science mapping (Donthu et al., 2021; Zupic & Cater, 2015). When describing the benefits and drawbacks of science mapping techniques, Zupic and Cater (2015) firstly explained that while citation analysis quickly reveals key studies in a field, it may be biased against newer studies that have not yet received many citations. Secondly, they contend that co-citation analysis is the most widely used and valid science mapping method. Mapping the studies that appear in the same reference lists reveals which schools of thought have the broadest impact on the field. However, for a pattern to emerge, studies must be cited together many times; thus, as in citation analysis, co-citation maps will not depict studies with a low number of citations. Lastly, while co-authorship analysis reveals the social structure of a field, co-occurrence analysis plays an important role in defining the field by mapping the actual content of studies. Different representations and interpretations of a single concept or theme may pose a problem for this type of analysis, however.

The literature provides many examples of bibliometric analyses similar to the present study. For example, Abramo et al. (2012) used bibliometric analysis to explore the contributions of Italian universities; Diem and Wolter (2013) investigated Swiss scientists in educational research; and Budd and Magnusson (2010) and Earp (2010) mapped higher education studies and journals. Additionally, while Laengle et al. (2017) traced trends from the *European Journal of Operational Research*, Merigo and Yang (2017) applied similar methods to analyze the *International Journal of Intelligent Systems*. Finally, Gümüş et al. (2020) analyzed the contributions of Turkish researchers to the field of Educational Leadership and Management, and Phelan (2000) conducted similar research on Australian scholars in international education. The present study focused on articles published between 2000 and 2020 in one of the prominent journals in the field of science education, JRST. Consequently, it is believed that the bibliometric structure of this journal (or any other prominent journal) will provide solid evidence of the current state of science education.

Methods

This study employed both descriptive and bibliometric analysis. Based on data from the Web of Science (WoS), and present the descriptive analyses as frequencies and percentages. Researchers have used various software applications to perform bibliometric analysis; VOSviewer used for this study.

Why VOSviewer? How does it Work?

Unlike programs that generate relatively restricted maps (such as SPSS and Pajek), VOSviewer was designed to create more detailed and wide-ranging bibliometric maps (Van Eck & Waltman, 2010). An understanding of VOSviewer terminology is necessary to grasp the working principles of the program; thus, an example based on Van Eck and Waltman’s (2010) instructional manual is provided here. In **Figure 1**, there are circles with labels and links that connect them. These labels differ according to the type of analysis conducted; they may include author names for co-authorship analysis or keywords for co-occurrence analysis. Assume that the given map is part of a

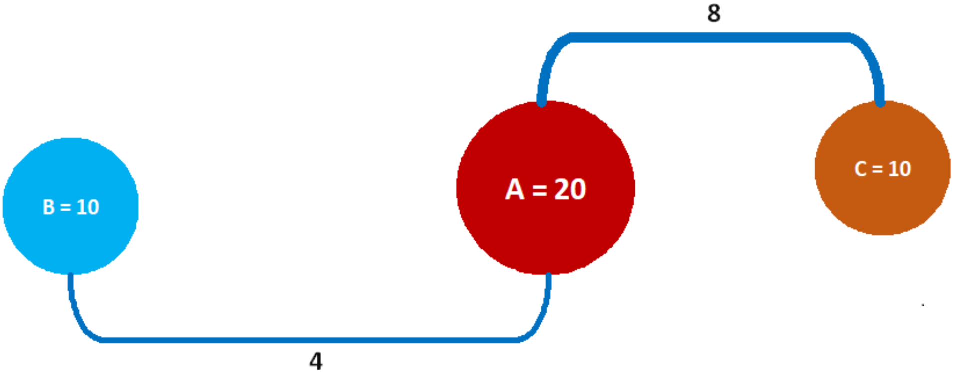

Figure 1. Working Principle of Vosviewer.

keyword analysis. Along with the keywords on the diagram, the frequency of occurrence is also indicated. The value next to the A keyword means that this keyword was encountered 20 times in the analysis. Suppose that the keywords B (blue) on the left and C (red) on the right are also seen 10 times. These frequencies are represented in the analysis program both by the size of the circles and the size of the labels. Thus, the circle and label for the A keyword are twice as big as those for the others.

The values of the links provide another important element for interpretation. The value "8" between the keywords A and C means that those two keywords are used together 8 times. Similarly, the value "4" represents the frequency of common use of the A and B keywords in the same study. In the analysis, these components, called link strengths, are shown in bold in proportion to the values they receive. The relative distance between the two objects also indicates these linkages. The link strength of the A keyword with the B keyword is 4, while the A keyword's link strength with the C keyword is 8. Therefore, in inverse proportion to these values, the distance between A and B is twice the distance between A and C.

Another key term is total link strength (TLS). TLS represents the total number of times the keyword is used together with all other keywords. In this case, while the TLS value of the A keyword is "12" (4 from A-B and 8 from A-C), and the keywords B (only A-B=4) and C (only A-C=8) are only related to A, their total link strength values are equal to their link strength values. Considering that the example given in the figure is only one part of a very large map, VOSviewer calculates the values of link strength for each of the keywords and total link strength for the other keywords, before grouping the concepts according to these linkages by arranging keywords that are frequently used with each other closely together and separating them from other keywords that are less frequently connected. These infrastructures, called clusters (represented by blue and red colors in the example), are determined by calculating keywords' total link strengths with each other. When the program generates clusters, it includes the group with the higher TLS value of the relevant keyword. Thus, we can say that the total link strength of the B keyword with the keywords in the blue cluster is more than that of the keywords it is linked to in the red group. Van Eck and Waltman's (2010) manual provides a more detailed explanation of this mechanism.

Selection of Sources and Data Analysis

The analysis procedure consisted of two phases (see **Figure 2**). The first phase involved selecting the data sources, while the second phase included the analysis and interpretation of the data.

During the first phase, data was obtained using the Web of Science (WoS) database. WoS provided all the bibliometric data required for this analysis. In addition, this source was preferred because it works in harmony with the VOSviewer software. As depicted in **Figure 2**, we followed the process recommended by Moher et al. (2009) when selecting the data sources (Phase 1). The first step of this phase involved the initial identification of the records through a basic search in WoS. To execute this search, the *Journal of Research in Science Teaching* was entered into the "publication name" tab, to limit the query to studies in this journal. For the purposes of the study, "2000–2020" was chosen as the time span. A total of 1218 documents were obtained as a result. In the second step (screening), these documents were reviewed and all proceedings papers (13), corrections (5), and editorial materials (104) were excluded. After a total of 122 studies were eliminated, all remaining documents were reviewed in the third step (eligibility) for duplication and erroneous sources. After it was determined that there were no errors, a total of 1096 studies were included in the study sample. Thus, the final search phrase used in the Web of Science to gather the data for this study on February 12, 2021 was as follows:

PUBLICATION NAME: ("journal of research in science teaching") Refined by: [excluding] DOCUMENT TYPES: (PROCEEDINGS PAPER OR CORRECTION OR EDITORIAL MATERIAL) Timespan: 2000-2020. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI.

The second phase of data analysis began with descriptive analyses in WoS's analysis tab using frequencies and percentages. General insights were provided by visualizing the document types (e.g., review or research article) of the publications in JRST, the number of articles published by year, and the countries and universities of the publishing authors. In the second step, which involved bibliometric analysis for identifying the intellectual structure

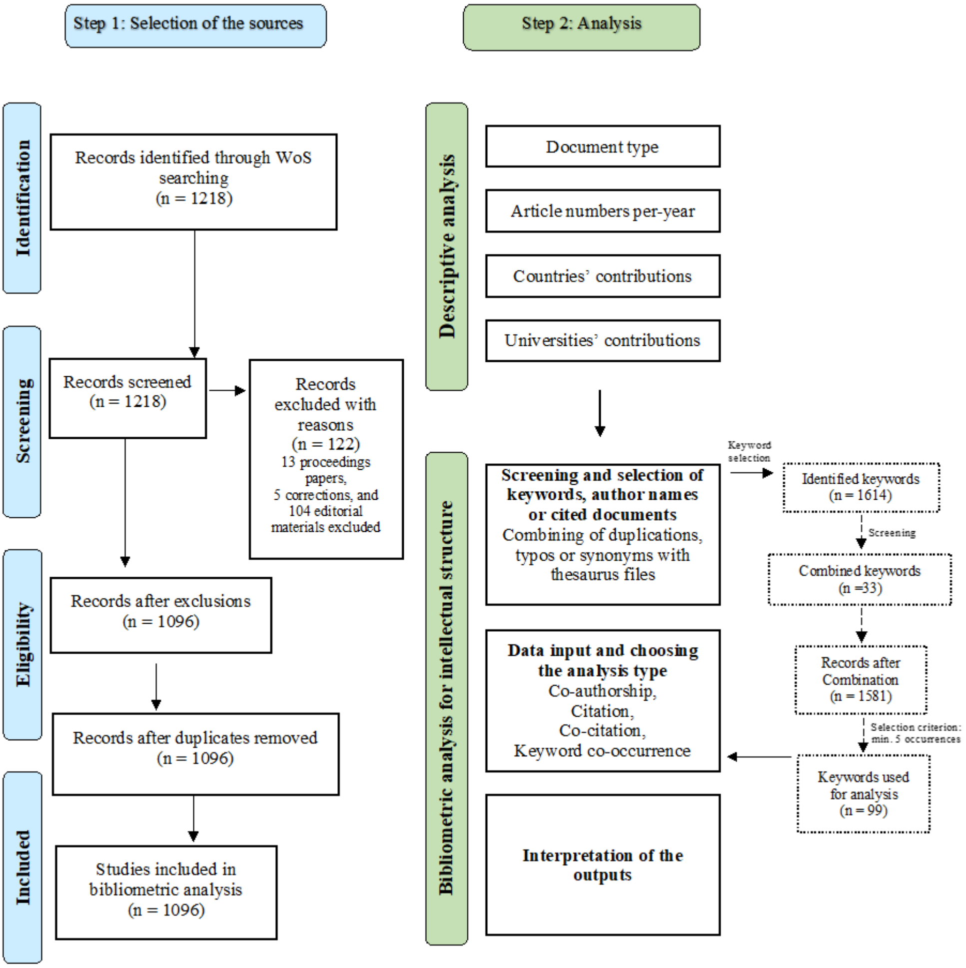

Figure 2. Selection of the Sources and Analysis.

of the journal, the previously downloaded data from the 1096 publications were transferred to VOSviewer for closer analysis. This process began with selection and screening of the keywords and author names. Since the software tries to create patterns using all the data during these analyses, it was important to first debug and correct any potential errors in the data. Thesaurus text files were used to prevent typos or redundant entries from causing unnecessary repetition in the results. For example, similar notations representing the same person or keyword in the WoS database, such as authors "Krajcik, J" and "Krajcik, JS," or keywords "socio-scientific issues" and "socioscientific issues" were combined.

Though the extraction logic employed in author and keyword analysis is similar, non-systematic keyword selection process is provided here as an example. As seen in **Figure 2**, the studies included in the data set contained 1,614 author keywords. Keyword screening revealed that 33 of these author keywords had similar representations, where they were paired with others in the study that had the same meaning but were worded differently by the authors. For example, keyword combinations (that are not open to interpretation) such as “learning progressions” and “learning progression” or “nature of science” and “nature of science (NOS)” were made. This data cleaning process narrowed the number of keywords to 1,581. Next, the software needed to be told which keywords to examine. When all data was used at the same time, a vastly complicated map with 1581 keywords was created. To create a simpler map, keywords that were used fewer than five times were eliminated, to narrow the keywords to the most established concepts in the field of science education. This yielded the 99 most frequently used keywords, which were then analyzed.

This study utilized bibliometric analysis parameters such as citation (for authors and documents), co-citation, co-authorship, and co-occurrence (Van Eck & Waltman, 2010). At the conclusion of data analysis, the two researchers, who are experts on bibliometry, separately examined the maps generated by VOSviewer to make the final inferences.

The results of the data analysis are presented in two sections, each corresponding with one of the study’s guiding research questions: the *descriptive analysis of the journal and intellectual structure of the journal* (following the categories described by Hallinger, 2020). The elements included in the descriptive analysis are outlined above. The second section presents an analysis of the journal’s intellectual structure. In this study, “intellectual structure” refers to a journal’s research traditions, interdisciplinary structure, and influential research subjects, as well as the pattern of relations among them (Zupic & Cater, 2015). According to Ramos‑Rodríguez and Ruíz‑Navarro (2004), frequently cited authors and documents have a greater influence on the field than those less frequently cited. Identifying the most influential authors and articles in a journal might therefore give insight into the journal’s intellectual focus. To identify these influential authors, co-authorship analysis was performed in VOSviewer to identify the document numbers, link strengths, and TLS values of the authors. Citation counts were also taken directly from WoS to identify the most influential documents. The date when the study was published online was considered when calculating the average number of citations.

Co-citation analysis reveals publications that are cited together in the same study (Hallinger, 2020). Similarly, examining the co-citations found in a study helps researchers make inferences about the focus of that study. Co-citation analysis typically reveals studies with similar content, which can be used as an important data source for estimating the focus of studies in a particular field (Díez-Martín et al., 2021; Ramos-Rodríguez & Ruíz-Navarro,

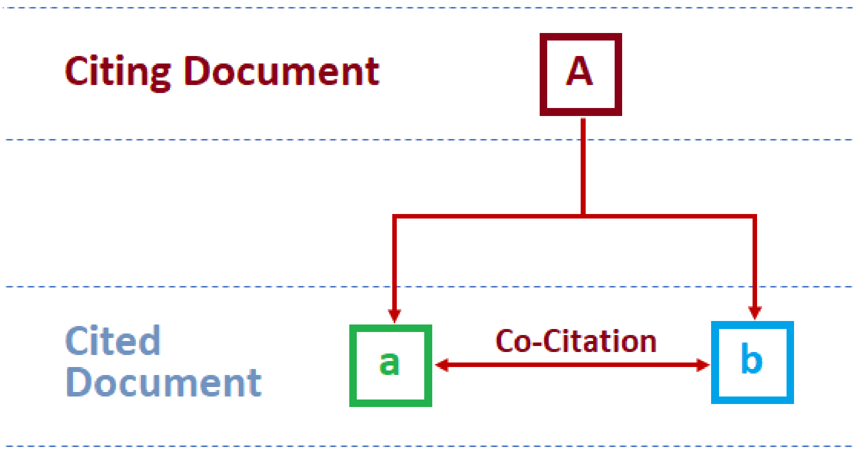

Figure 3. Representation of Co-Citation.

2004). **Figure 3**, designed by Vogel and Güttel (2013, p. 429), illustrates co-citation analysis of citing document A and cited documents a and b; thus, the number of times a and b are included in the reference list of the same document is calculated as their co-citation number.

Co-occurrence (keyword) analysis can also be used to identify a journal's intellectual structure. We employed author keywords for co-occurrence in this study by calculating the number of times these keywords were used both individually and together with other keywords. Co-occurrence analyses can provide researchers with accurate and reliable results about the topical foci in a journal or field (Gümüs et al., 2020). Consequently, combining co-authorship, citation count, co-citation and co-occurrence analyses enabled us to develop a big picture understanding of the JRST's topical patterns and intellectual structure over the last 20 years.

Study Limitations

This study aimed to illustrate the current trends in science education by analyzing the bibliometric data of the JRST from the past 20 years. However, it is important to highlight key limitations of this study's approach before interpreting its results. The most important limitation of this study involves the decisions made when selecting the keywords. As previously noted, only spelling issues or variations in the authors' notational preferences considered when deciding which keywords to combine. Even though several keywords may appear to represent the same meaning, all relevant research must be thoroughly analyzed before making a merging decision, since it is difficult to discern the authors' intent behind the keywords they chose to use (Zupic & Cater, 2015). As Gümüş et al. (2020) explain, the content of the studies cannot be examined in detail when working with such a large data set; thus, a researcher cannot determine the true intentions of the authors or studies in question. For example, the keyword "African American" was not included in the analyses since it was only used once, and therefore did not meet the criteria for inclusion in this study (at least five references). We therefore needed to examine the study itself to determine whether it should be combined with the "race" keyword. However, even reviewing such studies in order to proceed with keyword merging could fall prey to researchers' subjective opinions; thus, to minimize the potential of bias, we limited merges to spelling preferences only. Since the analysis program works on a single combination basis, it will be up to the researcher's decision whether to combine the keyword "African American" with "equity" or "race". Considering the working principle of bibliometric analysis, including eliminated keywords in the analysis could result in changes in the maps. As a result, one of the major limitations of the present study was that these potentially relevant keywords were not included.

Another limitation involves the keyword pool that journals provide when researchers submit their manuscripts. The JRST, like some other journals, asks authors to choose keywords from a pool for the review process when they first submit a manuscript. Although journals enable authors to add their own keywords after review, authors may choose to stick to keywords from the pool. This could lead to the frequent use of similar keywords in studies published in the journal.

Finally, because of the quantitative nature of this study, it avoids making some qualitative interpretations. It is obvious, for example, that inferring "influential" documents or authors in a field based on citation numbers is a significant limitation. In this context, it is important to remember that qualitative interpretations of the influential authors or documents in the JRST could limit the replicability and generalizability of this study's findings. With these limitations in mind, it is still reasonable to assert that this study offers meaningful implications for interpreting broad trends in the field of science education.

Findings

General Descriptive Analysis of JRST between 2000 and 2020

Table 1. Distribution of the Document Types.

Document types	Records	% of 1,096
Research article	1,069	97.54
Review article	27	2.46

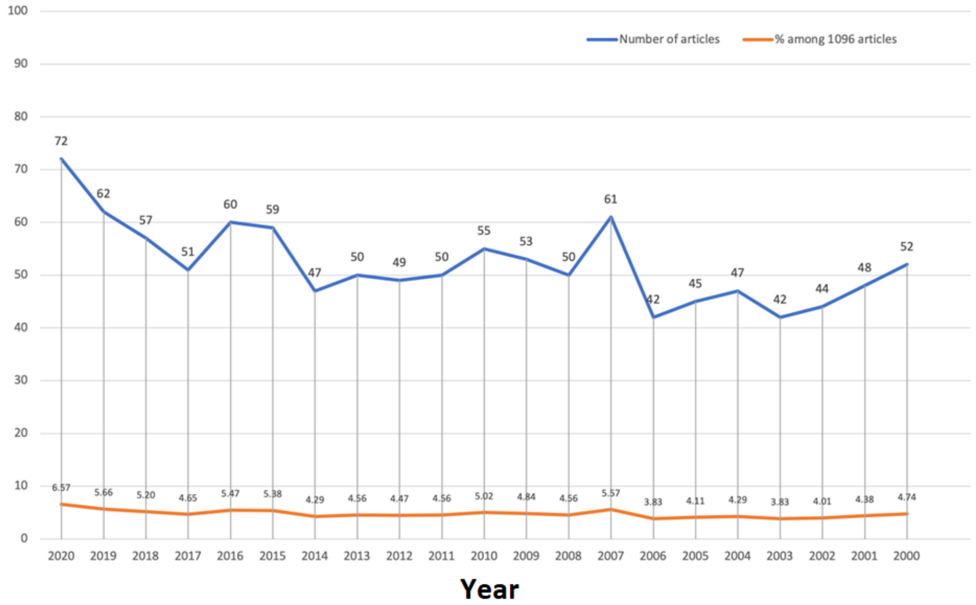

Figure 4. Annual Number of Articles Published in the JRST.

Table 1 shows the types of documents included in the analysis. Of the 1096 studies analyzed, 1069 were research articles and 27 were review articles. When the data were obtained, 15 of the studies were in the early access process.

Figure 4 shows the annual number of articles published in the JRST over the last two decades, as well as their percentage distribution based on WoS data. According to WoS data, the greatest numbers of studies were published in 2020 (72; 6.57%). However, since 15 of these studies were in the early access stage, this annual number appears high. The journal's web-site indicates that 57 research and review articles were published in 2020. On the other hand, 2003 and 2006 saw the lowest number of publications, with 42 articles (3.83%) each.

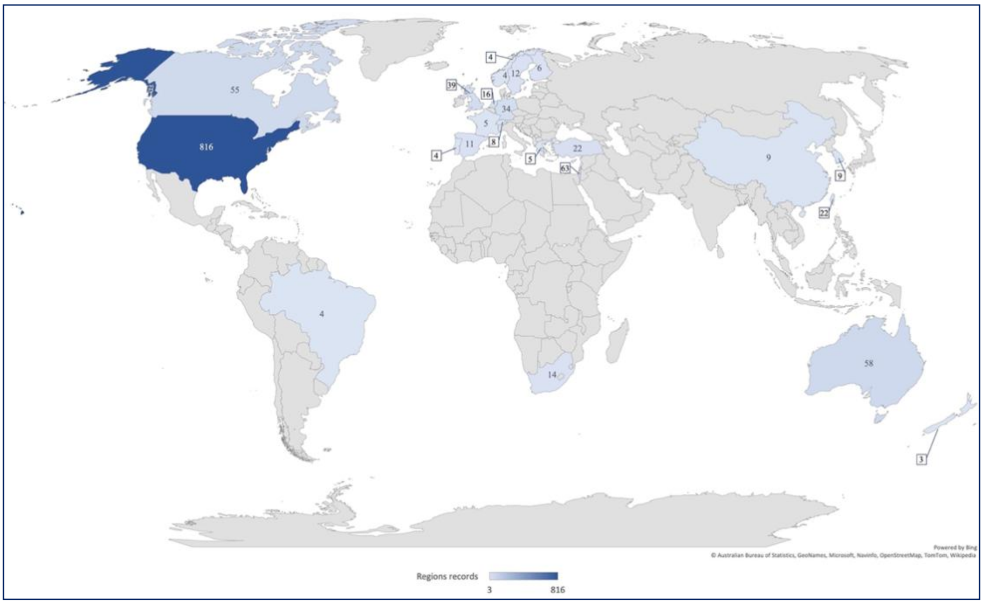

Figure 5. Distribution of Publications by Country.

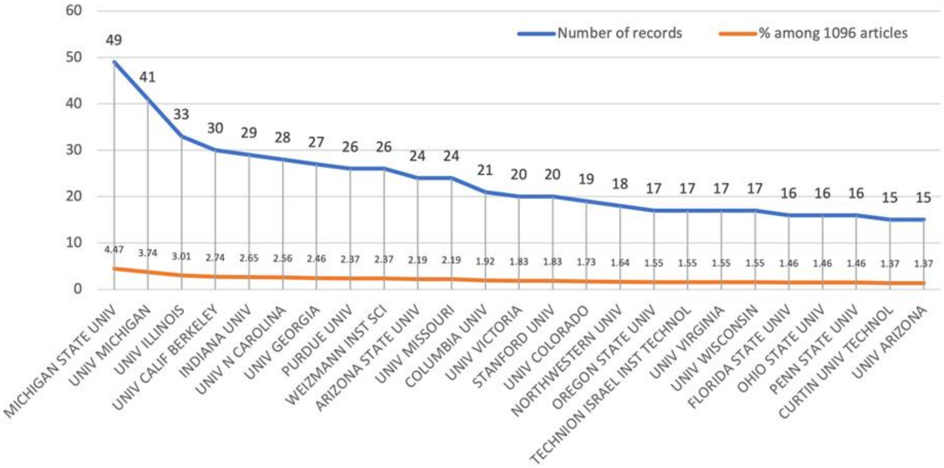

Figure 6. Distribution of Publications by Universities/Institutions.

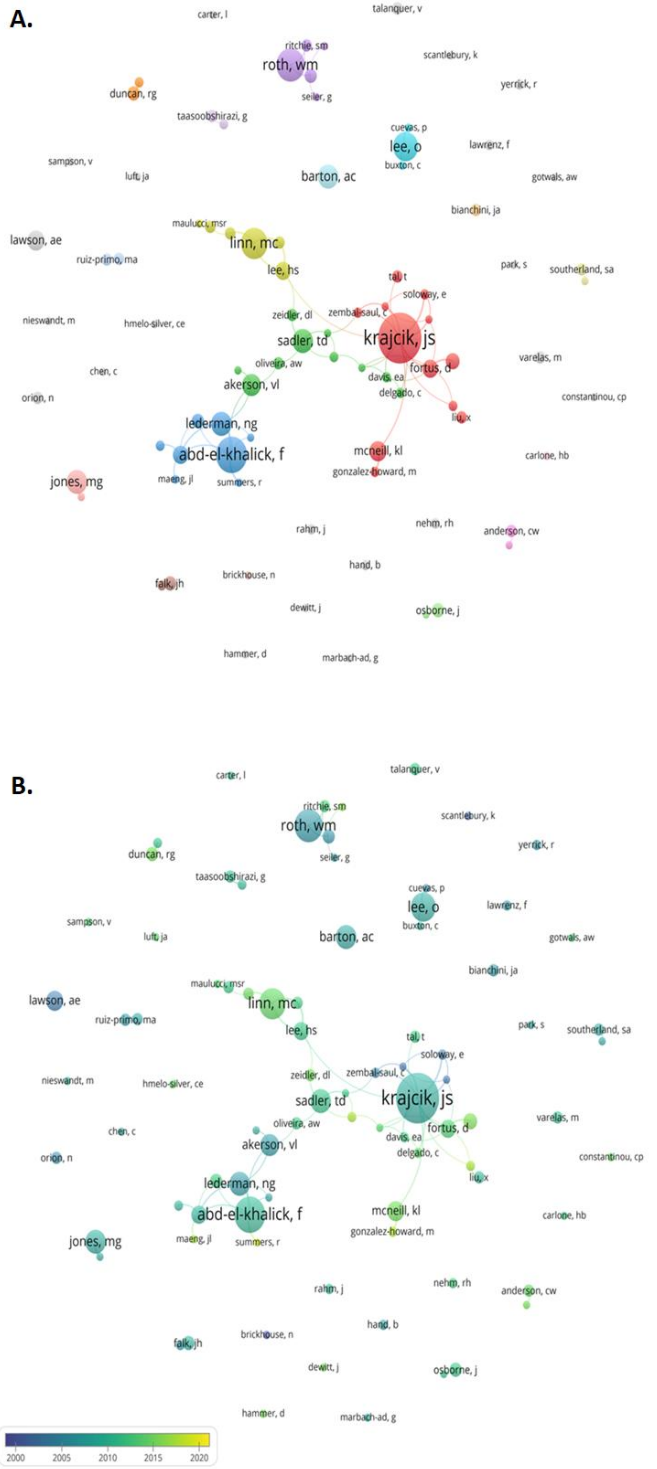

Figure 7. (A) VOSviewer Output for Co-Authorship Analysis. (B) VOSviewer Output for the Average Publication Years of the Authors.

Figure 5 identifies the countries where the studies in the dataset were conducted. This graphic, which depicts the 25 most referenced countries, shows that 816 (more than 70%) of the studies came from the United States, followed by Israel with 63 studies, Australia with 58, Canada with 55, and the UK with 39. Finally, Brazil (4), Norway (4), Portugal (4), and New Zealand (3) contributed the fewest studies among the top 25 countries. Countries shown in gray published fewer than three studies and were not among the top 25 countries.

Additional descriptive analysis was conducted to determine the authors' university affiliations. **Figure 6** shows the 25 universities that contributed the greatest number of studies to the journal during the 20-year period. Scholars from Michigan State University (49; 4.47%) contributed the most to the journal, followed by the University of Michigan with 41 studies (3.74%) and the University of Illinois with 33 studies (3.01%). Interestingly, 21 of the top 25 universities were in the USA. While Israel (the Weizmann Institute of Science and the Technion-Israel Institute of Technology) had two institutions on the list, Canada (the University of Victoria) and Australia (Curtin University of Technology) each had one.

Intellectual Structure of the JRST between 2000 and 2020

Co-authorship

Co-authorship analyses were conducted to identify the most productive researchers and research groups published in the JRST over the last 20 years. A VOSviewer visual illustrating this co-authorship analysis is presented in **Figure 7A**. A total of 2237 authors appeared in the analysis, with 86 authors having at least 4 publications. Although the authors who appear unconnected in the visual have at least 4 publications, they do not have co-authorship visuals due to their co-authors lacking at least 4 publications. The map shows several small groups, as well as four interconnected and dominant working groups. These clusters are shown on the map in green, red, yellow, and blue.

T.D. Sadler is the most influential researcher in the green cluster, with 12 papers. This green group establishes connections with other dominant groups, thereby acting as a unifying group, which is why it is located in the center of the map. This group has clearly established links with the yellow group through D.L. Zeidler and the blue group with V.L. Akerson. Sadler and colleagues focused their articles on socio-scientific issues, informal reasoning, and decision making. J.S. Krajcik is located in the center of the red cluster, another dominant group, with a total of 27 documents. Stud-

Table 2. LS and TLS of the Authors.

Author 1				Author 2				A1&2 LS
Name	DN	L	TLS	Name	DN	L	TLS	
Krajcik, J.S.	27	12	28	Soloway, E.	5	3	8	5
				Blumenfeld, P.C.	4	4	8	4
Abd-El-Khalick, F.	19	6	14	Lederman, N.G.	12	5	14	4
				Summers, R.	4	1	4	4
				Akerson, V.L.	11	4	7	2
Roth, W.M.	17	2	6	Tobin, K.	7	4	8	4
Linn, M.C.	16	3	10	Liu, O.L.	6	2	9	4
Sadler, T.D.	12	4	6	Zeidler, D.L.	7	2	3	3
McNeill, K.L.	10	2	7	Gonzales-Howard, M.	5	1	5	5
Fortus, D.	9	6	12	Vedder-Weiss, D.	8	1	4	4

***DN**: Document Number; **L**: Links; **TLS**: Total Link Strength; **LS**: Link Strength.*

ies in the red cluster tend to focus on project and inquiry-based classrooms. Beyond the red cluster, the map also indicates Krajcik's frequent collaborations with authors in the green cluster, making Krajcik the strongest link between the red and green groups. F. Abd-El-Khalick, located in the center of the blue cluster, has become one of the leading authors in terms of both productivity and partnerships, with 19 documents. This blue cluster indicates that Abd-El-Khalick's studies in partnership with N.G. Lederman, R.L. Bell, and R.S. Schwartz focused on nature of science (NoS) and scientific inquiry. Finally, M.C. Linn forms the center of the yellow group, with 16 documents. The studies of the yellow group are generally focused on assessment and dynamic visualization.

Additional influential working groups beyond these four dominant clusters are also pictured on the map. One of the most prominent was the violet group, which included W.M. Roth (17 documents) and colleagues. This group generally conducted studies on co-teaching, urban science education, and cultural diversity.

Table 2 shows the number of documents (DN) of the most influential authors who published in the JRST during the 20-year period, the number of different authors they worked with (L), and the number of times they collaborated with other authors in total (TLS). The last column of the table indicates the partnerships of the authors in the first and second columns (Link Strength: LS).

J.S. Krajcik stands out with 27 papers, collaborations with 12 separate authors, and 28 partnerships between 2000 and 2020. Krajcik collaborated most frequently with E. Soloway (5 times). Also prominent was F.

Table 3. Most Influential Documents of the JRST in the Last 20 Years.

	Title	Year	C	AVP
1	Views of nature of science questionnaire: Toward valid and meaningful assessment of learners’ conceptions of nature of science. ***Lederman, N.G.; Abd-El-Khalick, F.; Bell, R.L.; Schwartz, R.S.***	2002	723	36.15
2	Enhancing the quality of argumentation in school science. ***Osborne, J.; Erduran, S.; Simon, S.***	2004	589	32.72
3	Understanding the science experiences of successful women of color: Science identity as an analytic lens. ***Carlone, H.B..; Johnson, A.***	2007	555	37
4	Inquiry-Based Science Instruction-What Is It and Does It Matter? Results from a Research Synthesis Years 1984 to 2002. ***Minner, D.D.; Levy, A.J.; Century, J.***	2010	550	45.83
5	Fostering students' knowledge and argumentation skills through dilemmas in human genetics. ***Zohar, A.; Nemet, F.***	2002	530	26.5
6	Informal reasoning regarding socioscientific issues: A critical review of research. ***Sadler, T.D.***	2004	446	24.78
7	Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. ***DeBoer, G.E.***	2000	445	20.23
8	Developing a Learning Progression for Scientific Modeling: Making Scientific Modeling Accessible and Meaningful for Learners. ***Schwarz, C.V.; Reiser, B.J.; Davis, E.A.; Kenyon, L.; Acher, A.; Fortus, D.; Shwartz, Y.; Hug, B.; Krajcik, J.***	2009	443	34.08
9	Sources of science self-efficacy beliefs of middle school students. ***Britner, S.L.; Pajares, F.***	2006	401	25.06
10	Articulating communities: Sociocultural perspectives on science education. ***Lemke, J.L.***	2001	391	18.62
11	Professional development and reform in science education: The role of teachers’ practical knowledge. ***van Driel, J.H.; Beijaard, D.; Verloop, N.***	2001	388	18.48
12	Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders’ views of nature of science. ***Khishfe, R.; Abd-El-Khalick, F.***	2002	340	17
13	The effects of professional development on science teaching practices and classroom culture. ***Supovitz, J.A.; Turner, H.M.***	2000	334	15.18
14	Rethinking diversity in learning science: The logic of everyday sense-making. ***Warren, B.; Ballenger, C.; Ogonowski, M.; Rosebery, A.S.; Hudicourt-Barnes, J.***	2001	324	15.43
15	Facilitating Change in Undergraduate STEM Instructional Practices: An Analytic Review of the Literature. ***Henderson, C.; Beach, A.; Finkelstein, N.***	2011	309	28.09
16	Promoting understanding of chemical representations: Students' use of a visualization tool in the classroom. ***Wu, H.K.; Krajcik, J.S.; Soloway, E.***	2001	305	14.52
17	Influence of a reflective explicit activity-based approach on elementary teachers’ conceptions of nature of science. ***Akerson, V.L.; Abd-El-Khalick, F.; Lederman, N.G.***	2000	301	13.68
18	Learning to teach science as inquiry in the rough and tumble of practice. ***Crawford, B.A.***	2007	289	19.27
19	Embracing the essence of inquiry: New roles for science teachers. ***Crawford, B.A.***	2000	281	12.77
20	In search of pedagogical content knowledge in science: Developing ways of articulating and documenting professional practice. ***Loughran, J.; Mulhall, P.; Berry, A.***	2004	279	15.5

Abd-El-Khalick with 19 documents, 6 collaborators, and 14 total collaborations, including 4 collaborations with Lederman and 4 collaborations with R. Summers. As a final example, M.C. Linn was also a prolific author, with 16 documents, 3 co-authors, and 10 total collaborations, including 4 collaborations with O.L. Liu.

Co-authorship analysis determined that the average publication dates of the researchers varied between 2000 and 2018 (see **Figure 7B**). In the graphic, the darker colored circles represent those studies published in earlier years, while yellow tones indicate more recent publication dates. N. Brickhouse (2000), K. Scantlebury (2002), and A.E. Lawson (2003) had older averages, while R. Summers (2018), M. Gonzales-Howard (2017), and K. Neumann (2016) contributed to the journal more recently.

Influential Documents

Next, the analysis identified the 20 documents published in the JRST over the past two decades that had the greatest impact (**Table 3**). Citations of these studies from articles in JRST and all other journals indexed in the WoS database as of the date of data acquisition were evaluated. The impact of documents can be evaluated in two ways: the first involves identifying the most cited documents in the years in question, while the second involves calculating the average number of citations the study received over the years. According to the first method, the most cited paper was “Views of nature of science questionnaire: Toward valid and meaningful assessment of learners’ conceptions of nature of science” by Lederman et al. (2002). This study, which involves the VOSI scale—developed to determine the understanding of the nature of science—had 723 citations. The next most-cited paper was Osborne et al.’s (2004) “Enhancing the quality of argumentation in school science.” This article, which is among the foundational studies on the use of argumentation in science classes, has been referenced by authors 589 times. With their study titled “Understanding the science experiences of successful women of color: Science identity as an analytic lens,” Carlone and Johnson (2007) ranked third with 555 citations. This study has been the most prominent study of diversity and inclusion in science education in recent years.

Examining the average citations per year offers a different perspective. It is expected that older studies will receive more citations due to their longer shelf life. Therefore, assessing the average number of citations received per year allows us to make more reliable inferences about the effectiveness of a particular study in the field. In this context, the second and third studies in the top three are again Carlone and Johnson (2007) with 37 average citations and Lederman et al. (2002) with 36.15, while a paper titled “Inquiry-Based Science Instruction-What Is It and Does It Matter? Results from

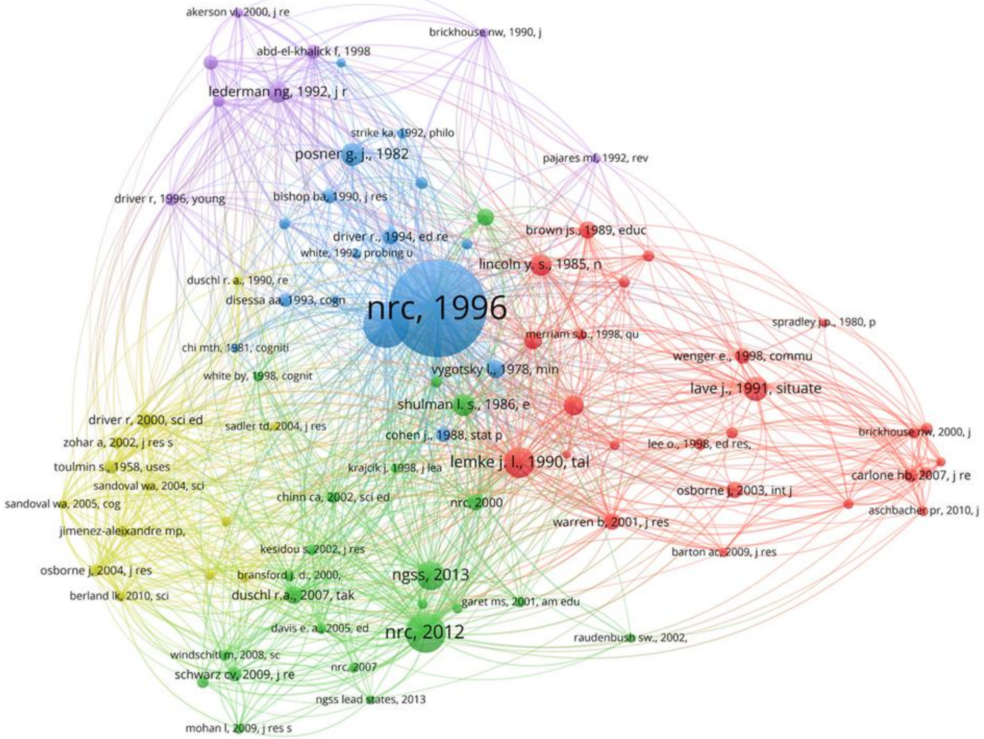

Figure 8. VOSviewer Output for Co-Citation Analysis.

a Research Synthesis Years 1984 to 2002" by Minner, Levy, and Century was the most prominent, with an average of 45.83 citations per year.

Co-citation

When conducting co-citation analysis of the 39,901 total references in the corpus of the present study, we selected studies with at least 25 references, to map a total of 85 studies (**Figure 8**). The WoS data includes only the first author of the cited document; thus, other authors are not presented on the map.

As depicted in **Figure 8**, five main clusters appeared during this phase of analysis. When looking at all the co-citation data, NRC (1996) (336 citations) and AAAS (1993) (148 citations) emerge as the most cited documents out of all the studies, and thus are in the center of the map. Since the blue cluster to which these studies belong is generally located in the center, it can be assumed that this cluster contains the field's most foundational documents. This group includes articles by G.J. Posner (1982), I. Vygotsky

(1978), T. Kuhn (1962), and R. Driver (1994) that played an important role in shifting the paradigm of science education. In addition to the centrally located blue cluster, the green cluster also represents shared thoughts, since it spreads to different points on the map. The most frequently cited document of the green group was published by the NRC (2012). In addition, the articles in this group by Next Generation Science Standards (2013), NRC (2000), R.A. Duschl (2007), and Shulman (1986, 1987) were also frequently cited and represent other basic studies of the field. The main difference from the blue cluster is that the green cluster mostly consists of studies published after 2000.

Three additional distinct clusters were identified, each clearly separated from the others. The first was the violet cluster at the top of the map, with N.G. Lederman (1992) at the center. The cluster, which includes additional documents by N.G. Lederman (2000 and 2002), as well as F. Abd-El-Khalick (1998 and 2000), N.W. Brickhouse (1990), and V.L. Akerson (2000), is mostly cited in studies centered around the Nature of Science (NoS).

Although it does not have a clear center, the studies in the yellow cluster are generally argumentation and reasoning oriented. This cluster includes documents by S. Toulmin (1958), R. Driver (2000), M.P. Jimenez-Aleixandre (2000), J. Osborne (2004), A. Zohar (2002), and T. Sadler (2004).

Finally, the studies in the red cluster mostly focus on inclusion in science education; thus, researchers working on issues such as equity, diversity, identity, and gender typically cite these documents. Examples include articles by H.B. Carlone (2004), N.W. Brickhouse (2000), and D. Holland (1998).

Table 4 shows the first authors of the most cited documents in the JRST from each cluster, along with their most frequently co-cited documents. NRC (1996) was most frequently cited with AAAS (1993), while NRC (2012) was most frequently cited with NGSS (2013), and Lederman (1992) was most frequently cited with Abd-El-Khalick (1998).

Co-occurrence Author Keywords

Of the 1581 total keywords included in the analysis, 99 had at least 5 occurrences. These 99 most frequent keywords were mapped, with a minimum cluster size of 15 for clearer reading of the results. As a result of the analysis, among the 99 keywords detected in the JRST between 2000 and 2020, 20 of the most frequently used keywords are presented in **Table 5**. The table also shows the clusters for the keywords, total link strength, and average publication year.

As seen in the table, science education, inquiry-based learning, and equity represented the most used keywords, with the strongest TLS. These

Table 4. Most Cited Documents by JRST Authors and Their Co-Citations.

Source 1				Source 2				S1&2 LS
Author Name	C	L	TLS	Author Name	C	L	TLS	
NRC, 1996	336	83	1226	AAAS, 1993	148	83	613	115
Lederman, N.G., 1992	63	67	373	Abd-El-Khalick, F., 1998	41	60	259	26
Driver, R., 2000	47	69	328	Zohar, A., 2002	35	64	267	21
NRC, 2012	127	81	594	NGSS, 2013	88	74	299	44
Lemke, J.L., 1990	96	78	432	Warren, B., 2001	49	64	258	15

***C**: Citations; **L**: Links; **TLS**: Total Link Strength; **LS**: Link Strength.*

Table 5. Most Seen Keywords and Descriptives.

Keywords	Cluster	Occurrences	Total Link Strength	Av. Pub. Year
Science Education	Red	82	172	2015
Inquiry-Based Learning	Green	66	141	2013
Equity	Red	43	109	2014
Secondary Science	Yellow	43	107	2012
Middle School Science	Red	41	94	2011
Chemistry Education	Yellow	41	77	2012
Nature of Science (Nos)	Yellow	40	81	2012
Professional Development	Green	39	83	2014
Physics Education	Red	37	89	2011
General Science	Red	35	89	2008
Assessment	Green	35	68	2014
Biology Education	Yellow	34	84	2011
Achievement	Red	32	75	2012
Science Teacher Education	Green	32	62	2013
Elementary Science	Blue	32	58	2013
Learning Progression	Green	32	46	2014
Curriculum Development	Green	31	83	2012
Teacher Education	Green	28	68	2014
Evolution	Green	28	55	2013
Socio-Scientific Issues	Yellow	27	50	2013

keywords—which have 172, 141, and 109 total link strengths, respectively—were the most used by researchers and consequently the most frequently associated with other keywords.

As represented in **Figure 9A**, the 99 most popular keywords were grouped under 4 clusters. The keywords in the blue, green, and red clusters are all clearly distinguished from other clusters. The yellow cluster, on the

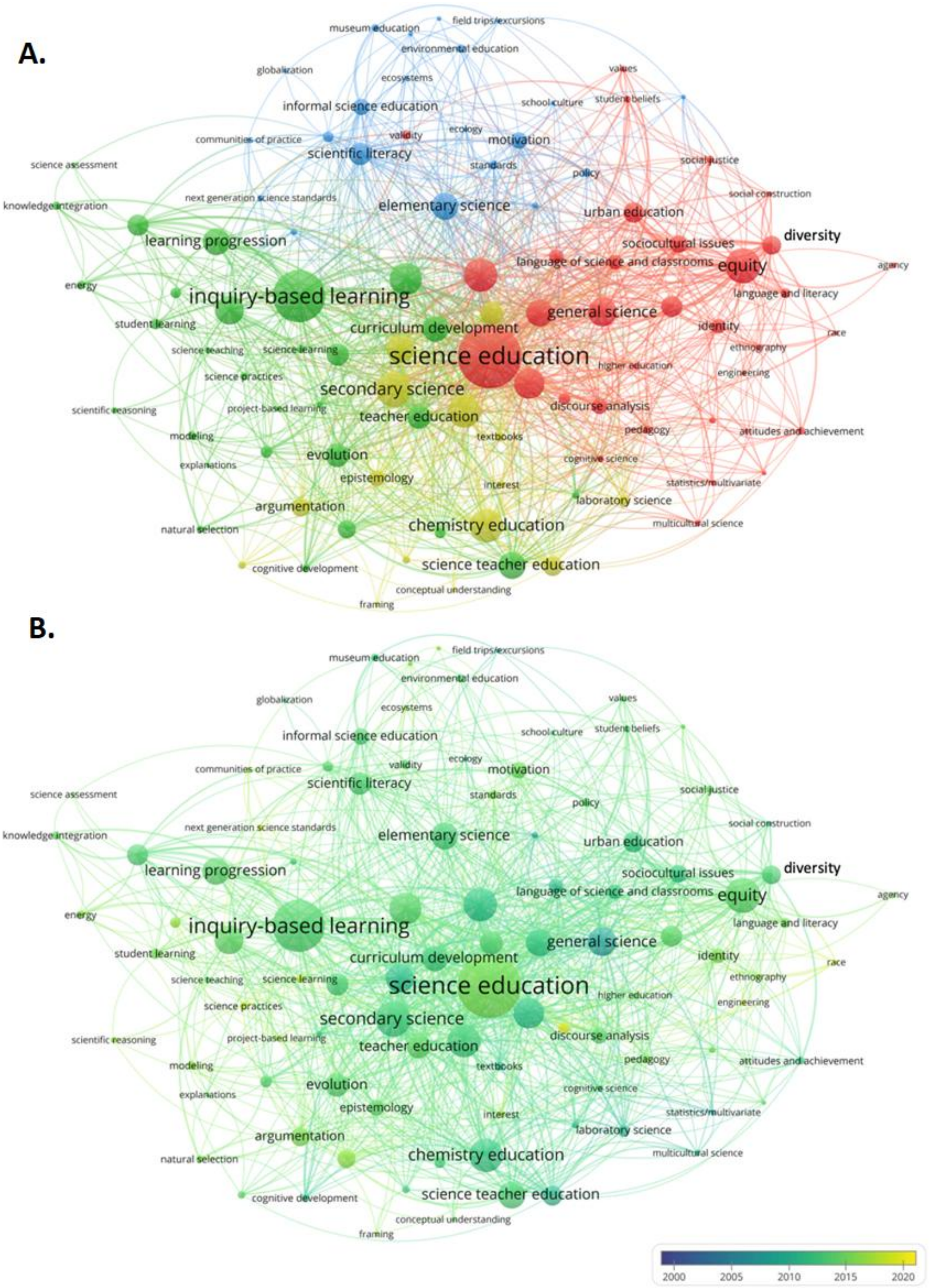

Figure 9. (A) VOSviewer Output for Co-Occurence Analysis. (B) VOSviewer Output for the Average Years of the Keywords.

Table 6. Link Strength of Most Used Keywords.

Item 1	Item 2	Link Strength
Equity	Diversity	10
	Science Education	7
	Socio-cultural issues	6
Inquiry-based learning	Curriculum development	10
	Technology education	10
	Professional development	7
Nature of Science (NOS)	Inquiry-based learning	7
	General science	6
	Socio-scientific Issues	6
Informal science	Museum Education	7

other hand, connects with all the other clusters. The science education keyword in the center of the red cluster also forms the center of the entire map. Most of the inclusive education keywords were found in this cluster, including equity (43 occurrences), gender (25), diversity (22), socio-cultural issues (20), identity (17), ethnography (6), race (5), multicultural science (7), urban education (24), social justice (8), and values (6).

In the green cluster, while inquiry-based learning (66 occurrences) was the central keyword, learning progression (32), conceptual change (26), evolution (28), misconceptions (13), science teacher education (32), pedagogical content knowledge (21), technology education (25), and assessment (35) were also typical agents of the cluster. Thus, the green cluster can be called a learning and teaching oriented cluster.

The blue cluster's keywords focus on informal science education. Scientific literacy (26 occurrences), informal science (19), museum education (8), environmental education (9), motivation (19), and field trips/excursions (5) are among the most frequently used words in this cluster.

Finally, the yellow cluster represents the basics of a new paradigm. This cluster is nested within the others, and thus collects concepts that reflect the paradigm shift in the field such as nature of science (40), epistemology (18), socio-scientific issues (27), and argumentation (22).

The frequencies of selected keywords in the map are shown in **Table 6**, which includes the most used keywords that represent each cluster. The keyword equity, which represents the red cluster, is frequently paired with the diversity (10), science education (7), and sociocultural issues (6) keywords in the same cluster. The inquiry-based learning keyword in the center of the green cluster, on the other hand, had 10 TLS with curriculum development and technology education and 7 TLS with professional development.

In the blue cluster, informal science was used 7 times with museum education.

Figure 9B shows the average years when the keywords were used between 2000 and 2020. While dark colors represent older years, light colors mean that the keywords were used more recently. Statistics/multivariate and general science were found to have the oldest average (2008) among the keywords. With an average publication year of 2019, the most recent keyword was STEM education. The average years in the inclusive (red) cluster were race, 2018; identity, 2015; agency, 2015; equity, 2014; and diversity, 2013. Average years in the learning and teaching (green) cluster were inquiry-based learning, 2013; learning progression, 2014; assessment, 2014; misconceptions, 2013; and conceptual change, 2013. In the blue cluster, the average years were 2013 for informal science education, scientific literacy, environmental education; 2011 for museum education; and 2009 for field trips/excursions. Finally, the average years in the yellow cluster were 2016 for pedagogical content knowledge, 2015 for argumentation, 2013 for socio-scientific issues, 2014 for epistemology, and 2012 for nature of science.

Discussion

When examining the overall image of the JRST from 2000 to 2020, one of the most striking findings is that more than 80% of the publication's authors hail from the United States, Australia, Canada, or the United Kingdom. Parallel to this result, 23 (92%) of the most prolific 25 universities that contributed are in the USA, Australia, or Canada. This result could be attributed to the leading role these countries have played in the paradigm change in science education. In these countries, the positivist-objectivist view of the nature of scientific knowledge is being replaced by a social constructivist epistemology (Irez & Han, 2011; Taylor et al., 1997). As a result, conceptual change research, a growing understanding of constructivism, and discussions on multicultural education have created changes in science education that began with the curriculum studies initiated in the post-Sputnik period and Kuhnian-inspired understandings from the 1970s (Matthews, 2004). Such large-scale educational reforms bring with them new conceptual frameworks, educational goals, and perspectives, which means a new world for researchers, teachers, students, and other stakeholders. Since paradigm shifts in a field tend to progress slowly, stakeholders who are resistant to change and hold onto previous paradigms can slow the pace of progress (Irez & Han, 2011). Considering that the paradigm shift in science education has a 50-year history, it is not surprising that the most popular studies included in this analysis tend to come from the first countries to adapt to this process of change. It is expected that the contributions of other countries will gradually increase; in fact, a review by Abd-El-Khalick et al. (2021) of JRST publications between 2015 and 2020 showed that non-US studies increased from 18% of the total articles in the journal in 2016 to 50% in 2019. The present study also confirmed the increasing trend of non-US studies over the past 20 years.

As stated previously, the co-authorship, influential documents, co-citation, and co-occurrence analyses provided important evidence about the dominant "schools of thought" within science education. Schools of thought, also referred to as "intellectual structures," represent the ideas and practices that dominate a field. This study concluded that although many authors have contributed to the JRST, certain authors came to the fore and contribute to the focus of the journal through their fields of study and influential publications. As stated in the findings section, J.S. Krajcik (project and inquiry-based classrooms), T.D. Sadler (socio-scientific issues, informal reasoning, and decision making), M.C. Linn (assessment and dynamic visualization), and N.G. Lederman and F. Abd-El-Khalick (nature of science and scientific inquiry) were among the most prolific researchers during the two-decade period. These authors not only have more publications than the other scholars published in the journal—they also worked with many other researchers, demonstrating a strong record of collaboration in their respective fields. Their working groups also connected with other groups, indicating that they frequently communicate and interact with the science education community. Additionally, W.M. Roth (co-teaching, urban science education, and cultural diversity) has been a prominent author independent of other working groups. The isolation of W. M. Roth and his working group from others can be read as a sign that these domains are not yet connected, which provides a critical gap for future work in this area.

The analysis of the most influential documents in the journal revealed that researchers most frequently referred to three domains of study: nature of science (Lederman et al., 2002), argumentation (Osborne et al., 2004), and science identity (Carlone & Johnson, 2007). The topic with the highest average of citations was scientific inquiry (Minner et al., 2010). Additional influential areas included socio-scientific issues (Sadler, 2004), sociocultural perspectives (Lemke, 2001) and scientific modeling (Schwarz et al., 2009). The productivity and citations of these documents confirm that they exemplify the trends within this field and, moreover, that they play an important role in shaping these trends (Pasadeos et al., 1998).

In co-citation analysis, documents that are cited together typically represent similar perspectives or philosophies. Thus, the close relations that emerge in these analyses can also give researchers messages about the intellectual structures that shape and drive the field. A similar condition, co-occurrence, is visualized through keyword analysis. Both the frequency and co-occurrence of keywords provide strong evidence of this intellectual structure (Hallinger, 2020). In the present study, three distinct school of thought groups emerged in co-citation analyses: NOS and scientific inquiry, argumentation, and inclusive science education. Likewise, when the keywords were examined, three additional groups stood out: teaching and learning, informal science education, and inclusive science education.

The combined results of these analyses demonstrate that the researchers publishing in the JRST focused on two key questions over the past 20 years: “Which science teaching methods and strategies are most effective?” and “What can be done to make science teaching more inclusive?” This result echoes the findings of Concannon et al. (2020), who stated that schools of thought centered around fostering students’ depth of knowledge of science and how it works have steadily strengthened over the last 30 years. As seen in the present study, the recent emergence of the STEM keyword in the literature represents a similar philosophy that has been fostered by these schools of thought.

Another school of thought contends that science education should be designed to include traditionally underrepresented minority groups. The science education community has embraced the mission of preparing a classroom environment that considers all these differences (Carlone, 2004). The constructivist approach to science education states that learners come to class with different prior knowledge, understanding, and cultural backgrounds—all of which are essential to creating educational experiences. These basic assumptions of the constructivist paradigm have led to the adoption of more inclusive education approaches (Matthews, 2002). As previously mentioned, recent popular topics in the JRST, such as STEM, appear to align well with inclusive education. In their analysis of studies on inclusive science education, Comarú et al. (2021) reported that STEM was the most used subject. Thus, strategies and practices from a constructivist approach—such as inquiry-based teaching, argumentation, socio-scientific issues, and STEM—can be employed to create more inclusive science classrooms. This inference leads us to conclude that these trends in science teaching should naturally lead researchers and practitioners to inclusive education. Our findings indicate that the JRST has paid special attention to the studies on inclusive science teaching and learning over the past two decades. Several notable efforts have pushed this issue into the spotlight, including a special issue, titled “Globalization in Science Education,” published in 2011. This issue focused on “building closer international cooperation with a particular emphasis on valuing and keeping cultural diversity” (Chiu & Duit, 2011, p. 553). Furthermore, a virtual issue project directed by Atwater (2011) centered on studies published in the JRST between 1980 and 2010 about multicultural science education, equity, and social justice. After evaluating 233 total articles on these topics, reviewers (12 science educators) for the issue selected the 9 most compelling studies to highlight for today’s science education community. As shown in the previous sections, the occurrence of keywords such as race (avg. year 2018), identity (avg. year 2015), equity (avg. year 2014), and diversity (avg. year 2013) increased after these two special issues. Lastly, the journal’s interest in inclusive science education is also supported by another special issue call titled “Community-driven: Evidence of and science implications for equity, justice, science, and participation,” announced in April 2021 (Ballard et al., 2021). This call signals continued interest in promoting “equity in science and science education,” which is also reflected through our bibliometric analysis of the JRST.

As previously stated, the difficult and time-consuming process of a paradigm shift in a field typically follows a set of natural stages. The first of these steps, as in all intellectual changes, involves identifying and speaking aloud the issue before change can be made. Since knowing something and doing something are two hugely different things (Pedretti & Hodson, 1995), it is critical that perceptions on the subject change first, both on an individual and community level (Levitt, 2002). This study shows that the science education community is trying to change perceptions on this subject; however, the field must also shift the focus of promoting equity in science education beyond mere rhetoric and towards concrete actions to build inclusive practices and structures in communities, schools, and the academy. As evident in the co-occurrence analysis, although the inclusive science education cluster has a significant place in the map, it is limited by its location at the periphery. It is critical that these keywords move to a central position just like the yellow cluster—that is, forming a fundamental philosophy that shapes all other study subjects. Indeed, this movement is critical not only for science education research, but also for understanding the “other” identities of us as citizens of the world (Mutegi et al., 2019).

Since many articles in the JRST have focused on empowering traditionally underrepresented students, teachers, and researchers in the field, it is worth considering why many of the most influential studies in the field come from white men. When the loudest voices speaking about an injustice related to identity do not belong to individuals who hold that identity, it signals a level of “invisibility” (Mutegi, 2013) for members of that community. For example, Avraamidou (2022) emphasized that school structures and culture can be alienating and intimidating for women. When racial disparities compound the difficulties that women face when attempting to reach the top of their profession (O’connor & Irvine, 2020), it creates a double bind for women of color (Nguyen et al., 2021). As Carlone and Johnson (2007) stated, these issues center around the academic world’s “recognition” of gender and racial identity. In an ideal world, all different identities would be “visible” and recognized by the academy (Hughes et al., 2021). The gradual filtration of stereotypes and discrimination based on identity, which begins in early childhood, has since manifested itself in an academic social structure dominated by white males.

The inadequacy of pre-college science and math education for people of color, according to Russell and Atwater (2005), is another source of this inequality, which in turn influences college major and career choices for these minoritized groups. Variables such as other students, teachers, the school's psychosocial learning environment, and the curriculum have an impact on the science learning of any underrepresented group (Atwater, 2000). A social constructivist understanding of learning holds power to address these issues, since it reveals how differences are reflected in learning in every sense.

Unfortunately, solely eliminating disparities in science and math courses is insufficient. As Mutegi (2013) writes, all types of discrimination should be perceived as a component of a much larger system of oppression (e.g., systemic racism), and such a system can only be addressed through a total shift in perceptions. Thus, studies investigating how social perceptions of markers of difference impact pre-college science education (such as Mutegi's 2013 study of African-American students) or interrogating the recognition and hierarchy of these identities in the science classroom (see Carlone & Johnson, 2007) are critical. Additionally, we should reflect on how teachers, academics, parents, and other stakeholders render these different identities "invisible" and discourage or prevent minoritized students (Mutegi, 2013) from pursuing science-related careers as a result. Finally, raising consciousness around the effects of microaggressions will help create a more equitable learning environment for students from minoritized groups (Mutegi et al., 2019).

To conclude, this study analyzing the publications of the JRST provides clues about the construction of scientifically literate societies, which represents the ultimate goal of science education. The image of the last two decades of the JRST demonstrates that, while great strides have been made in building science literacy, these advancements are insufficient if they do not involve all segments of society. The COVID-19 pandemic has cruelly demonstrated that a significant portion of the population remains scientifically illiterate, which has posed massive problems in mitigating the spread of disease. The only way to deal with a crisis like this is to take collective action. When this context is considered in conjunction with this study's findings, it becomes clear how vital equality is to both education and society, since an unequitable learning environment cannot produce a proactive community capable of addressing systemic problems. In this way, while the cost of COVID-19 is human lives, the cost of racism and discrimination may be the "lives" of entire societies.

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