A Bibliometric Review on Realistic Mathematics Education in Scopus Database Between 1972-2019

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Abstract: Despite receiving increasing attention from mathematics education scholars, there has not yet been any overall understanding of the current state of realistic mathematics education (RME). To address this gap, this study aims to provide a review of 288 studies on realistic mathematics education from the Scopus database between 1972 and 2019. Using descriptive and bibliometric analyses, this study addresses four research issues as follows: (i) the total volume, growth trajectory, and geographic distribution; (ii) the most influencing authors and research groups; (iii) the most influencing sources (i.e., journals, books, conferences); and (iv) the most important topics. Several implications for not only mathematics education scholars but also other stakeholders, including policymakers, school managers, mathematics teachers, may not be considered in this study.

Keywords: *Bibliometrics, mathematics education, mathematics in context, realistic mathematics education, Scopus.*

Introduction

'Realistic mathematics education' (RME) has emerged as one of the key trends in mathematics education (ME) over several previous decades. Realistic mathematics education (RME) has emerged as one of the key trends in mathematics education over several previous decades. The first ideas about RME were formed in the Netherlands during the 'Math War' as a new approach to teaching Mathematics in opposition to the 'New Math' movement in Europe around the 1960s (Wittmann, 2020). At that time, math education in the Netherlands was driven by mechanical teaching methods, in which the content originated from the structure of mathematics as a science; thus, the mathematics education programs and content were significantly separated from reality (Niss, 1996; Tien-Trung et al., 2020). Consequently, the students lacked learning motivation and failed to understand the practical significance of mathematics knowledge. A reform led by H. Freudenthal gave birth to a new school of mathematics education called 'Realistic Mathematics Education' (Wittmann, 2020).

Freudenthal (1973) considers mathematics to be a human activity. Thus, he believed that mathematics should not be a closed system but should be a practice of mathematizing activity and if possible, a mathematizing activity. The aim of RME, therefore, is to make math education more realistic, appropriate, and meaningful for the majority of learners. He argued that learners should be provided with/positioned into real-life situations so that they can reconstruct math knowledge (Treffers, 1993; Van den Brink, 1991). RME is characterised by diverse real-life situations which serve as sources to devise math concepts, instruments, and procedures and also provide a scenario for learners to apply the concepts they learn in the later stages as the context grows more abstract and general (Van den Heuvel-Panhuizen & Drijvers, 2014). In RME, the math and real-life relationship not only is present at the end of the learning process but also acts as a resource for the teaching and learning process (Do et al., 2021; Van den Heuvel-Panhuizen & Wijers,

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2005). Despite the importance of realistic situations, referring to real-life situations, the term 'realistic' means that students are asked to solve problems that they can imagine (Tong et al., 2022; Van den Heuvel-Panhuizen & Drijvers, 2014).

One of the key advantages of RME is the connectivity between human activities and mathematics concepts or the relevance to everyday situations of mathematic problems (Cheng, 2013). According to RME, students need to be 'learning math in context'; therefore, RME-based teaching requires a reform of teaching methodology (Sembiring et al., 2008; Trung et al., 2019). Learning activities need to be designed and organized in such a way as to challenge learners, make them more independent and able to think more critically and thereby better solve problems as 'mathematicians' (Tong et al., 2022; Zulkardi et al., 2020).

Along with the increasing popularity of RME in actual practice, academic scholars have also paid increasing attention to this topic. Previously, mathematics education scholars examined RME from different perspectives, such as innovating the process of teaching mathematics in high school (Laurens et al., 2018), training teachers using the RME theory approach (Nguyen et al., 2007), or the links between RME and contextual teaching (Fredriksen, 2021; Gravemeijer & Doorman, 1999; Vos, 2020).

Currently, RME has crossed the border of the Netherlands to reach more than thirty other countries around the globe, including the United States, England, South Africa, China, Korea, Indonesia (Van den Heuvel-Panhuizen, 2020a, 2020c). A number of countries have constructed a General Education Math Curriculum and textbooks of mathematics patterned after RME, including the Netherlands, the United States of America, Indonesia, and South America (Oldham et al., 1999; Tien-Trung et al., 2020). RME has proven to be an effective method to help both average and below-average learners better grasp abstract math concepts (Sembiring et al., 2008). Additionally, RME has been shown to enhance learners' active participation in class (Revina & Leung, 2019; Tinh et al., 2021; Tong et al., 2022), promote flexibility in the learning program (Revina & Leung, 2019; Sembiring et al., 2008; Trung et al., 2020) and improve student learning attitudes in the math classroom (Tong et al., 2022). In each country, RME is adapted in a way that is in line with the local culture, practice, and educational policies or objectives. In the USA, for instance, context-based math education programs and materials, so-called Mathematics in Context (MiC) (Van den Heuvel-Panhuizen, 2003), have been developed while in Indonesia, such programs are referred to as PMRI, or Pendidikan Mathematika Realistik Indonesia (Indonesian Realistic Mathematics Education) (Zulkardi et al., 2020).

In 1969, bibliometric analysis was used to quantitatively evaluate scientific activities based on the form and content of the scientific literature (Pritchard, 1969). The basic bibliometric analysis uses descriptive statistics to document "topographical" trends within a body of knowledge (Hallinger & Kovačević, 2019) and illuminates the evolution of a knowledge base (White & McCain, 1998). This method is also can be used to identify the trend within a research field and its evolution over a period of time (Binh et al., 2021; Thi-Trinh et al., 2021).

Bibliometric analysis has been widely used to analyse scientific evolution of various research fields such as higher education (Hallinger & Chatpinyakoop, 2019), sustainable development (Hallinger & Nguyen, 2020), lifelong learning (Thi-Trinh et al., 2021), social sciences (Pham et al., 2020), Science, Technology, Engineering and Mathematics (STEM) education (Ha et al., 2020) and mathematics education (Julius et al., 2021; Lozada et al., 2021; Özkaya, 2018). However, the application of these bibliometric tools to mathematical educational research is rare (Drijvers et al., 2020).

Furthermore, the few bibliometric studies on mathematics education have not included any mention of RME, nor have any studies analyzed the RME quantitatively to assess the development of this research trend in ME field. Nevertheless, in his report at the Freudenthal 100 symposium, Wittmann (2005) pointed out that RME is an important trend in Mathematics education.

Thus, this study aims to fill this gap by seeking to document and synthesize patterns of previous research in RME over the previous decades. Specifically, four following research questions (RQ) would be examined:

RQ1. What are the total volume, growth trajectory, and geographic distribution in the RME literature?

RQ2. Which authors and research groups have had the greatest impact on 7the RME literature?

RQ3. What sources (i.e., journals, books, conferences) have had the greatest impact in the RME literature?

RQ4. What are the most important topics in the RME literature?

Methodology

Bibliometrics was firstly introduced by Pritchard (1969) as a new approach to conduct review work. To date, it has been employed in different research topics (Patra et al., 2003), including mathematic-related ones. For example, Özkaya (2018) used 9,941 documents indexed in Web of Science between 1980 – 2018 to draw up the general layout of the scientific knowledge and communication structure of the field of mathematics education. These studies adopted different techniques of bibliometrics analysis (i.e., statistic descriptions, co-author analysis, science mapping) to

identify the knowledge base of their studied topics. In the same vein with these studies, this research analyzes 282 Scopus-indexed documents between 1972 – 2020 to address the four mentioned-above research questions.

Relational co-magnetic analysis allows us to explore the RME topic structure, identify topics of greatest research interest, and also reveal research trends in this topic (Zupic & Čater, 2015). Co-occurrence keyword recording shows the most common keywords appearing in the analyzed documents (Callon et al., 1986) to conclude that certain documents have the same topic and are related if they share some of the keywords defined in the keywords section.

Search Criteria and Identification of Sources

Scopus and Web of Science are the two most important academic databases, which have been usually used in prior bibliometric analyses. However, in this research, the Scopus database is selected as the source of documents instead of Web of Science. This is due to three reasons: First, Scopus employs a consistent standard in selecting documents for inclusion in its index. Second, it features a wider range of documents than the Web of Science for reviews of research in education and the social sciences (Hallinger & Chatpinyakoop, 2019; Hallinger & Nguyen, 2020). Third, some important outlets in mathematics education, such as For the Learning of Mathematics (ISSN: 0228-0671); Investigations in Mathematics Learning (ISSN: 1947-7503); The Mathematics Enthusiast (ISSN: 1551-3440) appear to not be indexed in Web of Science, but Scopus. Given these above rationales, Scopus was employed in this study.

To collect data, this study followed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for the document search (Ha et al., 2020; Hallinger & Nguyen, 2020; Mohamed et al., 2020; Pham et al., 2021) (see Figure 1). In the identification step, two keywords, 'realistic mathematics education' and 'mathematics in context' was used for a search query on the Scopus database. All documents whose titles, abstracts, or keywords identified with these two keywords were filtered. This is to ensure that the most relevant documents needed for the RME can be found. Specifically, the search query is as follows: TITLE-ABS-KEY ("realistic mathematics education*" OR "Mathematics in context*")

The above search query yielded 304 documents, which was further screened in the second step. Specifically, in the screening step, a set of parameters were adopted to refine the appropriate documents: (i) Document type: unlimited; (ii) Language: English; (iii) Subject area: unlimited; and (iv) Publishing year: unlimited. In this step, two documents were eliminated due to a lack of abstracts. Thus, 302 documents were furthered in the third step (eligibility). In the third step, we investigated every single document by reading its title and abstract. Each member was assigned the task of reading and making recommendations for keeping or removing certain documents from the chosen documents collection. At the end of this step, all the members discussed the rationale for eliminating a certain document from the analysis data. The research group re-investigated the title, abstract, and sometimes the full-text article to determine if it should be rejected or not. At this step, 20 documents were eliminated due to their irrelevant contents with RME (e.g., Clark & Sengupta, 2019). The final dataset is composed of 282 documents of which all were saved in a CSV file for further bibliometric analysis.
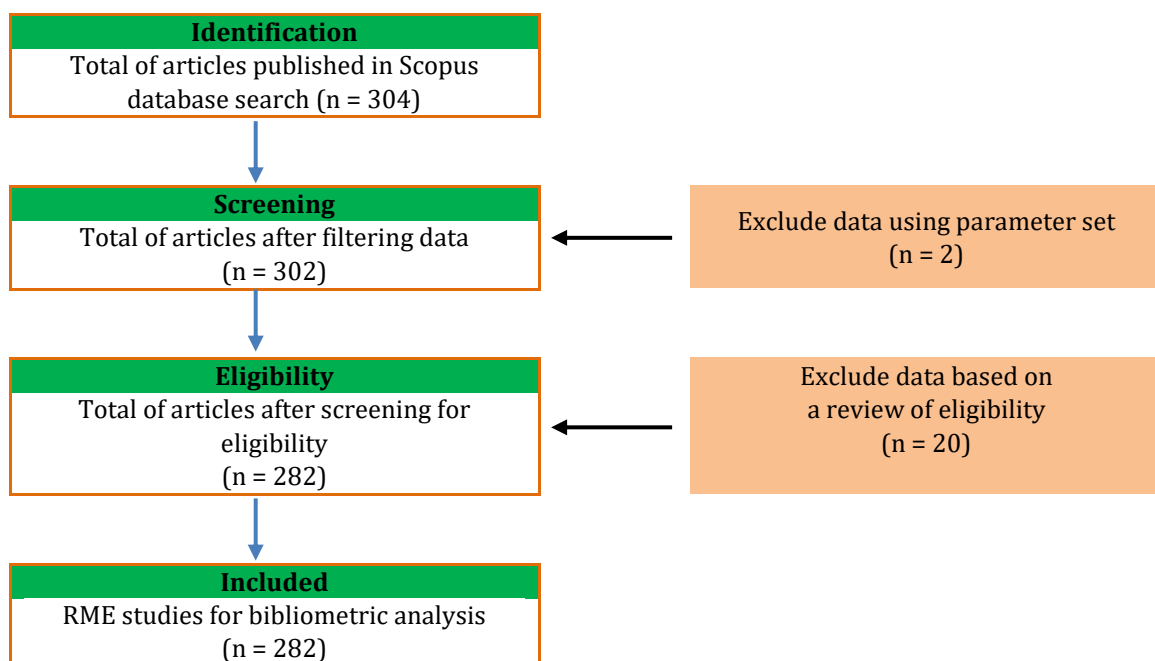

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)

Results

RQ1. What is the total volume, growth trajectory, and geographic distribution in the RME literature?

In this sub-section, we present the results regarding the first research question. Specifically, our four-step PRISMA searching and identifying process yielded 282 RME-related documents of which 257 articles were published in 57 journals (91.13%), were published in 16 books or book chapters (5,67%); and 9 were published in conferences (3.2%). Regarding timeline, Figure 2 presents the number of RME-related documents published between 1972 and 2020. The year of 1972 marked the first year that an RME document was published and indexed in the Scopus database (see May, 1972). It does mean that only four years after the initiative of RME by Freudenthal (1968), the first Scopus-indexed RME-related document was published. Nevertheless, the period of 1972-1992 (20 years) still did not receive adequate attention from the ME scholar community as there were only three RME-related documents published in this time span. Apart from May (1972), the two other documents are Ray (1974) and Streefland (1986).

The period of 1994-2011 (17 years) observed a stronger increase in RME research with overall 51 documents published within this period (3 papers/year). Nevertheless, not a single year in this period enjoyed a two-digit number of RME – related publications. The year of 2012 marked the first time that the number of RME-related publications surpassed 10 papers/year. Nevertheless, it appears that the annual number of RME-related documents returned to the downward trend from 2012 to 2015 with 15, 14, 11 and 9 documents, respectively. The most recent five years (2016-2020) witnessed a significant surge in the quantity of RME-related documents. Specifically, there were 178 RME-related documents published in this period, accounting for 63.12 % of the total 282 documents.
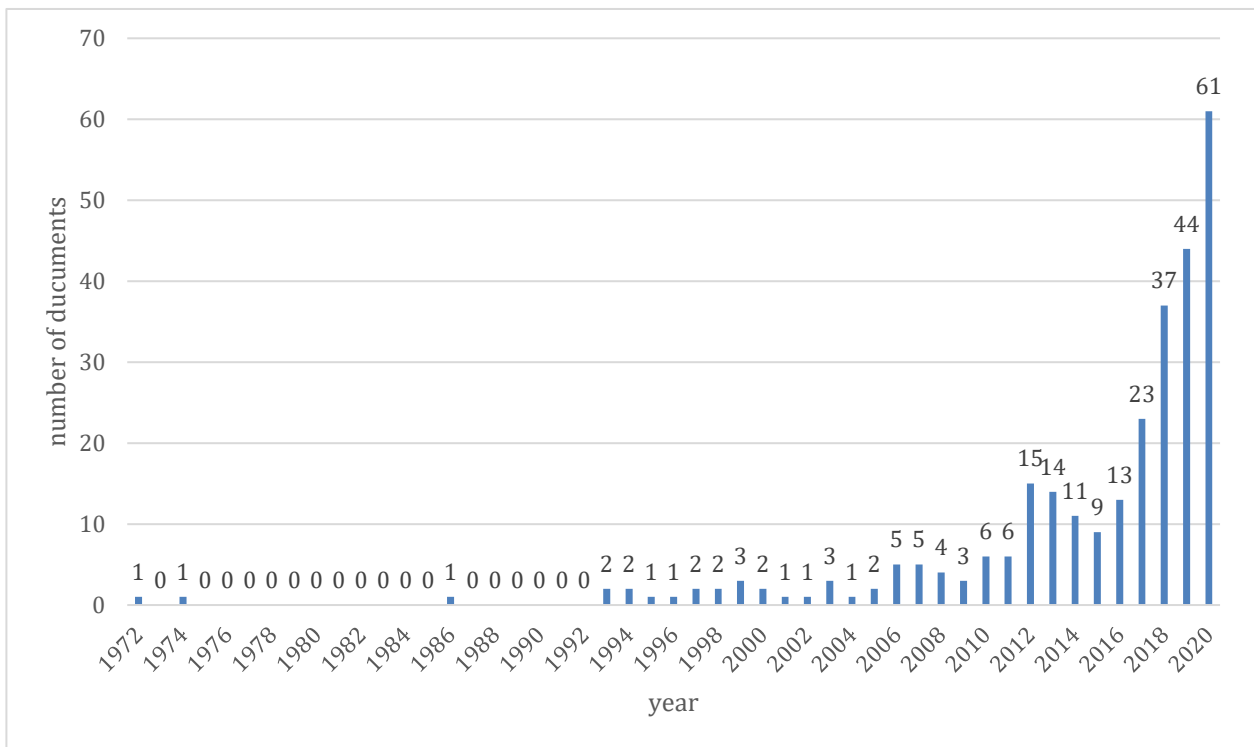

Figure 2. The Number of Publications Related to RME between 1972 and 2020 (N = 282)

Regarding the geographical distribution of RME-related documents, it appears that Indonesia, the US and Netherlands are the three most important countries in RME studies (in the total of 30 countries and 592 authors). To be more precise, scholars from Indonesia published 164 RME-related documents, which is equal to 58.15% of the total 282 publications. The figures for the US, Netherlands and Greece are 37 documents (13.12%), 28 (9.92%) and 11 (3.9%) respectively. As shown in Figure 3, all other countries only have one-digit number of RME-related documents.
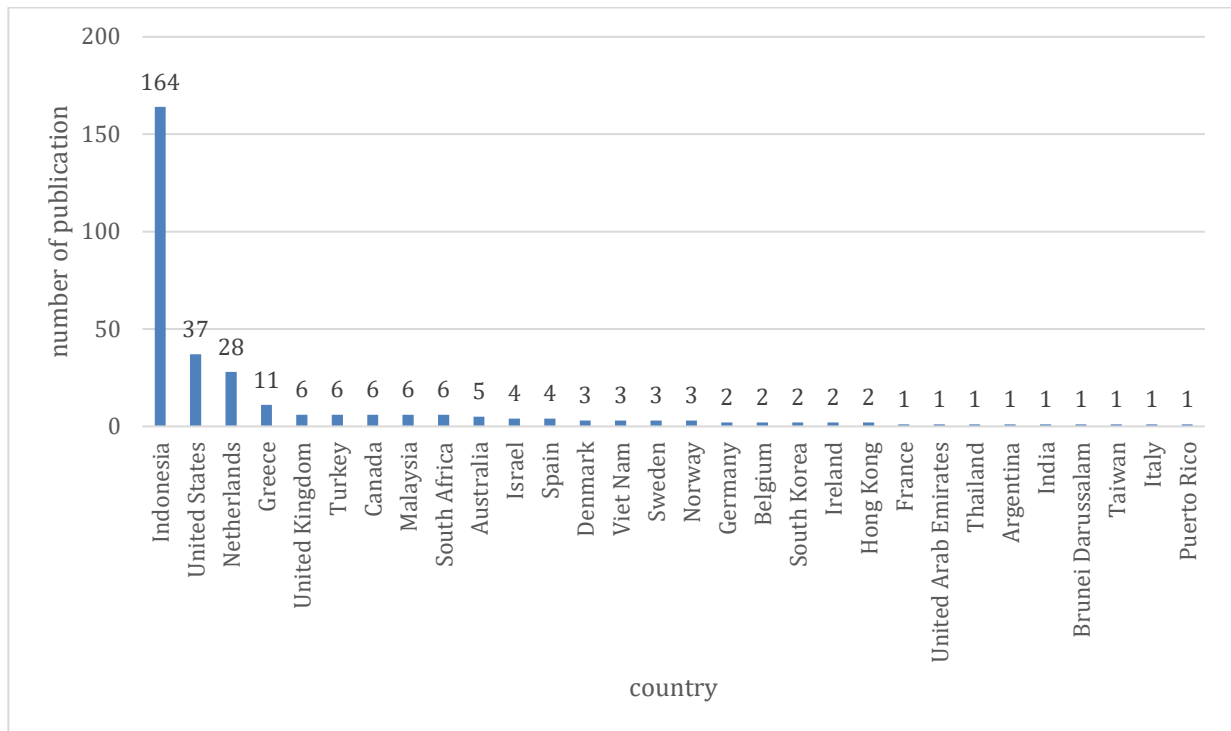
Figure 3. Number of Publications in RME by Countries between 1972 and 2020 (n = 282)

In order to further understand the collaboration between RME scholars from different countries, we used VOSViewer to conduct a science mapping representing the co-authoring patterns. As shown in Figure 4, each node represents one country. The size of each node represents the quantity of RME-related documents published by authors from the respective country. The line connecting two nodes represents the co-authoring activities of authors from the two countries. The wider the line is, the more documents were co-authored by the respective countries. As shown in Figure 4, Indonesia-Netherlands, Indonesia-Malaysia and the US-Netherlands are the three most prolific collaborations. Specifically, 56 documents were co-authored by scholars from Indonesia and Netherlands; while the figures for Indonesia-Malaysia and the US-Netherlands are 21 and 19, respectively. Surprisingly, there has been no document co-authored by scholars from the US and Indonesia in spite of the fact that these two countries are the two most productive countries in RME studies.
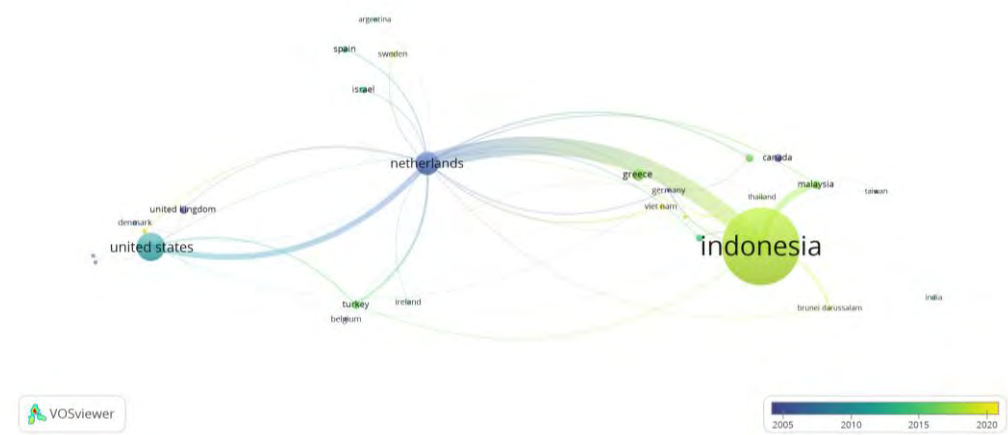

Figure 4. Science Mapping of Countries Collaborating in RME Research between 1972 and 2020 based on Co-authorship Analysis (Note: Number of Countries: 30; Number of Publication of Countries: at least a Document)

Apart from co-authoring patterns, Figure 4 also represents the recency of different countries on RME research. The node with dark color (purple or navy) implies that the authors from a respective country were involved in RME research a long time ago (prior to 2010). The most notable node with color purple is the Netherlands. Indeed, prior to 2010, there were 14 documents co-authored by scholars from this country. This contributed to 50% of the total RME-related documents before 2010.

The node with color "Persian green" represents countries that firstly joined RME research between 2010 and 2015. The most noticeable "Persian green" node is the US. The first US's RME-related document is Meyer (1997).

Indonesia, as colored in yellow, is the most prolific represented country involved in RME research after 2015. It is interesting to note that despite participating in RME research later than many other countries, Indonesia has become the most important hub of RME studies only within 10 years since first publication on RME (see Sembiring et al., 2008). A closer look at the detailed dataset revealed that the year 2017 marked an important milestone of RME studies in Indonesia. By 2016, Indonesia had only 31 RME-related documents, which was similar to the US's (32) and the Netherlands' (25). Nevertheless, the period of 2017-2019 witnessed an unprecedented surge of RME published by Indonesian scholars with 133 newly issued documents. Meanwhile, at the same time, there were only five more RME-related documents from the US and three more from the Netherlands. To explain the unprecedented jump of RME-related documents from Indonesia, we should take a close look at the extant policies on mathematics education in this country. Specifically, according to (Zulkardi et al., 2020) thanks to the close connection with the Netherlands, RME was introduced to the mathematics education community in Indonesia firstly in the mid-1990s. During the decade of the 2000s, a project called the Dutch-Indonesian project for Dissemination of PMRI (Do-PMRI) established a sustainable foundation for the development of RME in Indonesia until recent time. The development of RME in recent times may stem from six key activities, including: "(1) the International Master's Program on Mathematics education (IMPoME); (2) the International Conference on Design Research (SEA-DR); (3) the Mathematical Literacy Contest (KLM) and the Context-Based Mathematics Tasks Indonesia (CoMTI) project; (4) the web portal on PMRI set up by the P4MRIs; (5) the Course on Realistic Mathematics Education for Junior Secondary School Mathematics Teachers in Southeast Asia (SEA-RME course), and (6) the Journal of Mathematics Education (JME)" (Zulkardi et al., 2020)

RQ2. Which authors and research groups have had the greatest impact on the RME literature?

Table 1 represents the top authors of RME in terms of the number of RME documents and the number of citations. Interestingly, there is a significant divergence between two ranks (by documents and by citations), that is, authors with the most documents on RME maybe not be those with the most citations and vice-versa.

For instance, Fauzan published 12 documents on RME (ranked 1 in terms of documents) only has 26 citations in total (not included in the top 10 in terms of citations). In the opposite direction, it's accounted that Van den Heuvel-Panhuizen received a total of 232 citations (ranked 1 in terms of citations) but published only four RME documents (ranked 10 in terms of documents).

Authors from Indonesia seem to dominate the top 10 RME authors in terms of documents. Among 16 authors in the top 10 RME authors in terms of documents (it's noted that there are 6 authors ranked number 10 with four publications), 12 come from Indonesia. Meanwhile, the US and Netherlands seem to dominate the top 10 RME authors in terms of citations. Among 10 authors in the top 10 RME in terms of citations, four come from the US and three from the Netherlands (see Table 1).

Another interesting finding from Table 1 is that among the top authors, either in documents or in citations, Freudenthal, the 'father' of the RME, cannot be found. This can be explained by the fact that Freudenthal's first works on RME are written in German and are not indexed in the Scopus database. Furthermore, the argument of Streefland (1986) also provides a possible interpretation for this finding: '*Freudenthal laid the foundation for this didactical realism and determined the development of various learning strands, but more indirectly than directly because he himself did not design or outline themes and learning strands*.' (Treffers, 1993). Nevertheless, a closer look at the detailed dataset revealed that despite Freudenthal does not appear on the top author lists, his colleagues at Freudenthal Institute (Utrecht University) have contributed significantly to the RME literature with 22 documents (and 581 citations).

Table 1. Top 10 Authors Based on Number of Publications and Citations in RME between 1972 And 2020

Top 10 RME authors in terms of documents				Top 10 RME authors in terms of citations			
Rank	Author	Affiliation	Docu-ments	Rank	Author	Affiliation	Citati-ons
1	Fauzan A.	Universitas Negeri Padang, Indonesia	12	1	Van den Heuvel-Panhuizen M.	Freudenthal Institute, Utrecht University, Netherlands	232
2	Armiati A.	Universitas Negeri Padang, Indonesia	11	2	Doorman M.	University of Wisconsin, Madison, United States	213
3	Putri R.I.I.	Universitas Sriwijaya, Indonesia	9	3	Gravemeijer K.	Freudenthal Institute, Netherlands	167
4	Rasmussen C.	San Diego State University, United States	8	4	Rasmussen C.	Department of Mathematics and Statistics, San Diego State University, United States	148
4	Zaranis N.	University of Crete, Greece	8	5	Zandieh M.	Arizona State University, Department of Applied Sciences and Mathematics, College of Technology and Innovation, United States	93
4	Yerizon Y.	Universitas Negeri Padang, Indonesia	8	6	Prahmana R.C.I.	Master Program on Mathematics Education, Graduated Program, Universitas Ahmad Dahlan, Yogyakarta, Indonesia	87
7	Arnawa I.M.	Universitas Andalas, Indonesia	6	7	Drijvers P.	Freudenthal Institute, Utrecht University, Netherlands	85
7	Zubainur C.M.	Universitas Syiah Kuala, Indonesia	6	8	Marrongelle K.	Department of Mathematics and Statistics, Portland State University, United States	82
9	Suparman	Ahmad Dahlan University, Indonesia	5	9	Artigue M.	Université Paris Diderot-Paris 7, Paris, France	64
10	Van den Heuvel-Panhuizen M.	Utrecht University, Netherlands	4	9	Blomhøj M.	Roskilde University, Roskilde, Denmark	64
10	Doorman M.	Utrecht University, Netherlands	4	/	/	/	/
10	Prahmana R.C.I.	Universitas Ahmad Dahlan, Indonesia	4	/	/	/	/
10	Zulkardi, Putri R.I.I.	Universitas Sriwijaya, Indonesia	4	/	/	/	/
10	Julie H.	Sanata Dharma University, Indonesia	4	/	/	/	/
10	Abdullah D.	Universitas Malikussaleh, Indonesia	4	/	/	/	/
10	Rahman A.A.	STKIP Bina Bangsa Meulaboh, Indonesia	4	/	/	/	/

In order to investigate how the RME scholars work together to form research groups, we used VOSViewer to draw a science mapping that concerns the co-authoring patterns of the authors. As shown in Figure 1, there are 529 authors, who published at least one RME document between 1972 and 2019. Apart from 35 authors who published RME documents as solo authors, the other 494 formed 158 research groups, with the majority (133 groups) having less than five authors. There are seven research groups with at least 10 authors; of which five were led by scholars from Indonesia, one by a scholar from the US, and another by a scholar from the Netherlands (see Table 2).

Table 2. The Major Research Groups in RME Studies

Head of group	Affiliation	Number of co-authors
Putri R.I.I	University of Sriwijaya, Indonesia	20
Fauzan A	Universitas Negeri Padang, Indonesia	18
Abdullah D.	Universitas Malikussaleh, Indonesia	16
Prahmana R.C.I	Universitas Ahmad Dahlan, Indonesia	15
De Haan D.	Utrecht University, Netherlands	14
Rasmussen C.	San Diego State University, United States	13
Armiati A.	Universitas Negeri Padang, Indonesia	13

Similar to Figure 4, the node's color in Figure 5 reflects the recency of the respective author in RME studies. As shown in Figure 5, all "traditional" research groups (color purples) are from the Western world, such as De Haan d.'s (Netherlands), Rasmussen C.'s (the United States), Den Hertog J.'s (Netherlands), Middleton J.A.'s (the United States), Romberg T.A.'s (the United States); meanwhile, all "newly emerging" research groups (color green or yellow) are from Indonesia, such as Putri R. I. I's or Fauzan A.'s.
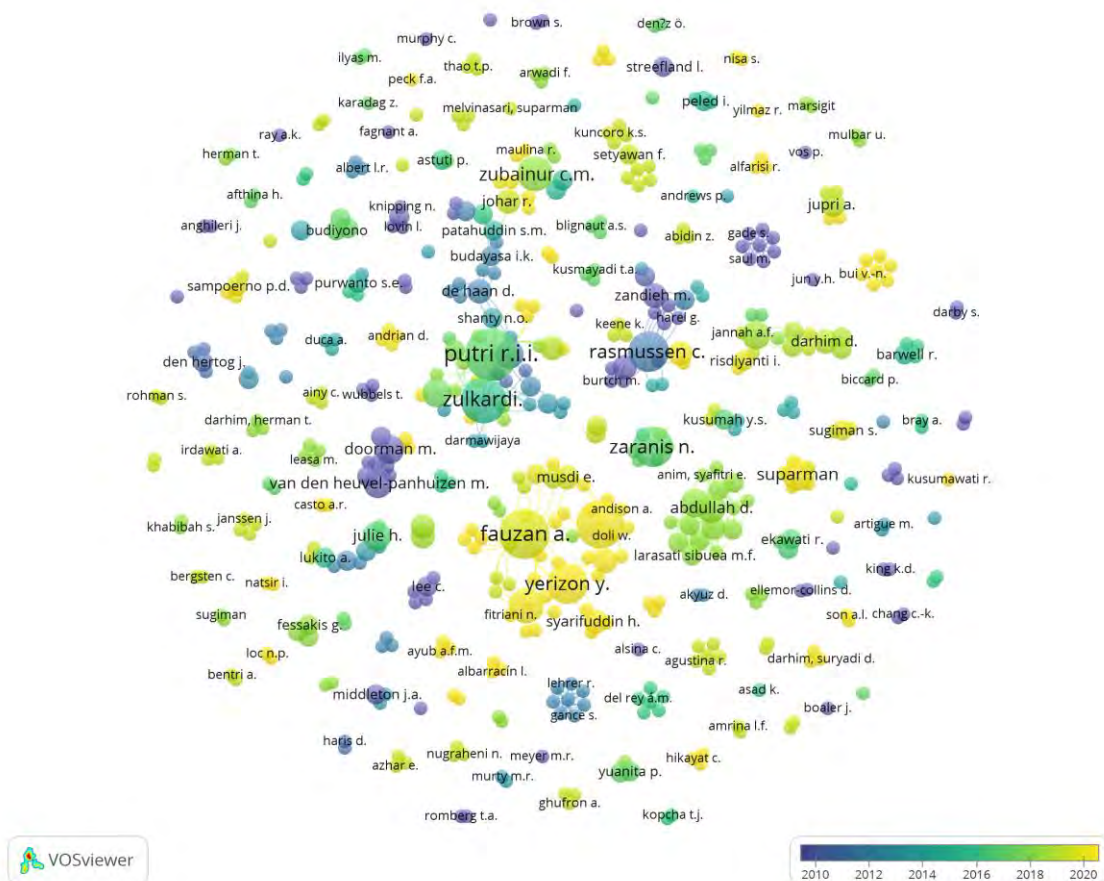

Figure 5. Science Mapping of Co-authors in RME Overtime between 1972 an 2020
(Note: 529 authors, each author has at least a document)

RQ3. What sources (i.e., journals, books, conferences) have had the greatest impact in the RME literature?

Table 3 showcases the top sources of RME studies based on the number of RME-related documents as well as their citations. Regarding the number of documents, the top five sources include Journal of Physics: Conference Series (SJR 2020 = 0.21), Journal on Mathematics Education (SJR 2020 = 0.51), International Journal of Scientific and Technology

Research (Discontinued in Scopus as of 2020), Journal of Mathematical Behavior (SJR 2020 = 1.33), and Educational Studies in Mathematics (SJR 2020 = 1.85); meanwhile, regarding the number of citations, the top five sources include Educational Studies in Mathematics, Journal of Mathematical Behavior, ZDM - International Journal on Mathematics Education (SJR 2020 = 1.2), Journal of Physics: Conference Series, Journal on Mathematics Education. Unlike what was observed from the top authors, our findings regarding top sources reveal that there are more significant common sources between the two top lists. To be more specific, there are seven sources, including Educational Studies in Mathematics, Journal of Mathematical Behavior, ZDM - International Journal on Mathematics Education, Journal of Physics: Conference Series, Journal on Mathematics Education, Journal for Research in Mathematics Education and International Journal of Mathematical Education in Science and Technology, have been found in both two top lists (see Table 3).

Table 3. Top 10 Sources based on Number of Publications on RME and Their Citations between 1972 and 2020

| Top 10 RME sources in terms of documents				Top 10 RME sources in terms of citations			
Rank	**Source**	**Source type**	**Document**	**Rank**	**Source**	**Source type**	**Citation**
1	Journal of Physics: Conference Series	Conference and Proceeding	85	1	Educational Studies in Mathematics	Journal	519
2	Journal on Mathematics Education	Journal	29	2	Journal of Mathematical Behavior	Journal	216
3	International Journal of Scientific and Technology Research	Journal	15	3	ZDM - International Journal on Mathematics Education	Journal	187
4	Journal of Mathematical Behavior	Journal	13	4	Journal of Physics: Conference Series	Conference and Proceeding	126
5	Educational Studies in Mathematics	Journal	11	5	Journal on Mathematics Education	Journal	110
6	AIP Conference Proceedings	Conference and Proceeding	10	6	Journal for Research in Mathematics Education	Journal	107
7	ZDM - International Journal On Mathematics Education	Journal	6	7	British Educational Research Journal	Journal	86
8	International Journal Of Mathematical Education In Science And Technology	Journal	6	8	International Journal of Mathematical Education in Science and Technology	Journal	75
9	International Journal of Science And Mathematics Education	Journal	6	9	World Transactions on Engineering and Technology Education	Journal	50
10	Journal for Research in Mathematics Education	Journal	4	10	Educational Psychologist	Journal	48
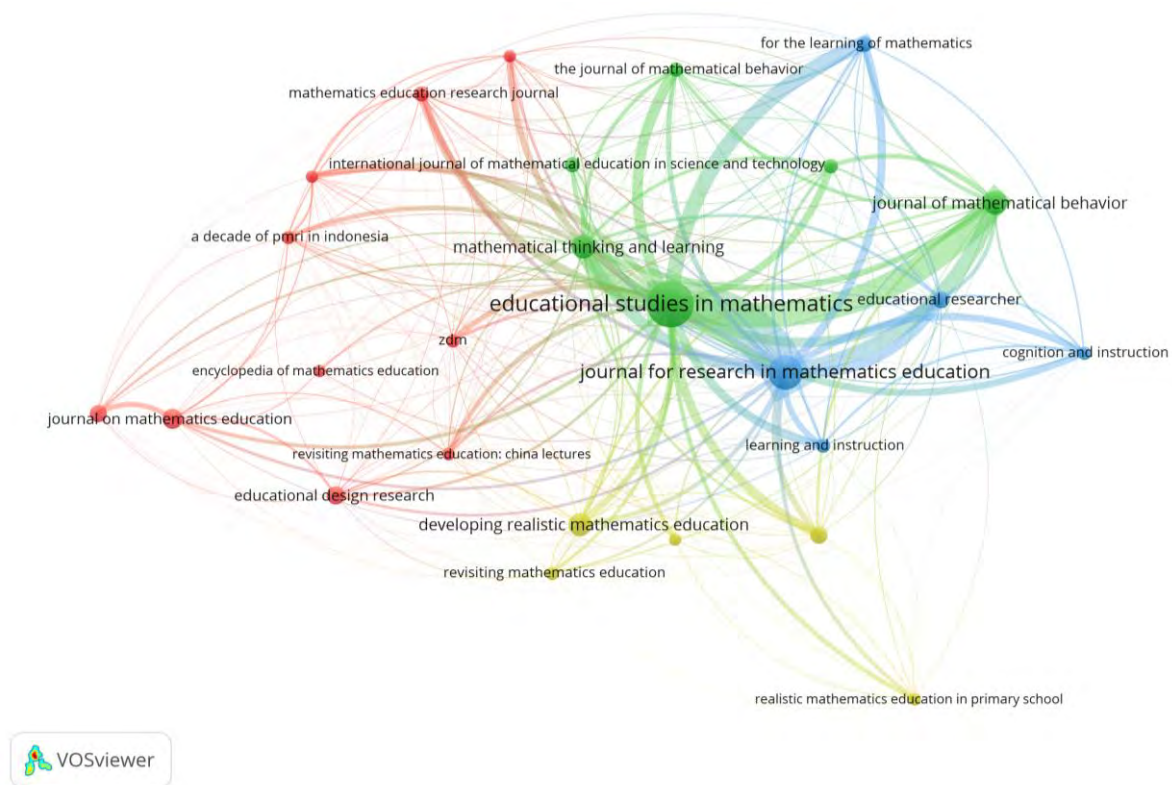
Figure 6. Science Mapping of Source Relationship base on Sources Co-citation Analysis on RME between 1972 and 2020
(Note: Number of Sources: 26; Number of Co-citation of Sources: At least 20 Citations)

Descriptive analysis as shown in Table 2 does not reflect all extent of influence of related sources. In order to have more detailed pictures of impactful sources in RME studies, we followed Pham's suggestion (Pham et al., 2021) to conduct a co-citation sources analysis. Figure 6 represents our co-citation analysis with 26 sources of RME-related documents with a minimum of 20 co-citations. From this figure, it may be induced to four clusters of RME sources:

(i) The red cluster, which is composed of ten sources. The key sources of this cluster include Journal of Physics: Conference Series, Journal on Mathematics Education, Educational Design Research.

(ii) The green cluster, which is composed of six sources. The key sources of this cluster include Educational Studies in Mathematics, Mathematical Thinking and Learning, Journal of Mathematical Behavior.

(iii) The blue cluster, which is composed of five sources. The key sources of this cluster include: Journal for Research in Mathematics Education, Educational Researcher, For the Learning of Mathematics

(iv) The yellow cluster, which is composed of five sources. The key sources of this cluster include Developing Realistic Mathematics Education, Mathematics as an Educational Task, Revisiting Mathematics Education.

It's noted that most of these 26 sources of RME-related documents appear to be relevant to education. Particularly, there are eight sources relating directly to mathematics education, including Educational Studies in Mathematics, International Journal of Mathematical Education in Science and Technology, International Journal of Science and Mathematics Education, Journal for Research in Mathematics Education, Journal of Mathematical Behavior, Journal on Mathematics Education, Mathematics Education Research Journal, ZDM - International Journal on Mathematics Education. This finding is, to a larger and lesser extent, different to what was observed from other bibliometric analysis in the education sector. For instance, Pham et al. (2021) studies on international students mobilities in Asia (ISMA) found that ISMA-related documents not only cite from international education or education-related sources, books and conferences but also from sources in other subjects such as behavioral sciences or tourism. This implies that ISMA studies have an interdisciplinary knowledge base. This is in contrast to the finding of this current study, which appears that RME-related documents are mostly based on monodisciplinary educational sciences.

RQ4. What are the most important topics in the RME literature?

To answer this research question, we undertook the co-keyword analysis using VOSViewer. Keywords are attributed to their respective documents. Each document would have around 4-6 keywords. Figure 7 represents the network of co-keyword synthesized from our database. Each node represents a keyword. Node's size reflects the frequency that the respective keyword appears in the selected RME documents. The color indicates the recency of the respective keyword. As shown in Figure 7, apart from "realistic mathematics education" (89 times), other most frequent keywords include

design-based research (20 times), ICT (Information Communication Technology) (9 times), PMRI (Pendidikan matematika realistik Indonesia) (9 times) and a fraction (7 times).

As these keywords are co-occurred simultaneously, it's worthwhile to count the most co-occurring couples or triples of keywords. Specifically, the highest-profile co-occurring couples of keywords include realistic mathematics education, design-based research (10 times); realistic mathematics education, ICT (5 times) and realistic mathematics education, reinvention (5 times); meanwhile, the most important triples of keywords include realistic mathematics education, design-based research and ICT.

We may also want to consider the most important keywords emerging recently. To address this issue, we would look at the yellow nodes in Figure 7. It can be seen that the "hottest" RME topics in recent times include Flipped classroom (Voigt et al., 2020), Algebraic thinking (Apsari & Putri, 2020), Contextual problem (Reinke & Casto, 2020), Mathematical communication (Armiati et al., 2019), Addie (Chairil Hikayat et al., 2020), e-module (Chairil Hikayat et al., 2020), influence of culture (Revina & Leung, 2019), number pattern (Fauzan & Diana, 2020), emergent models (Rasmussen et al., 2019).
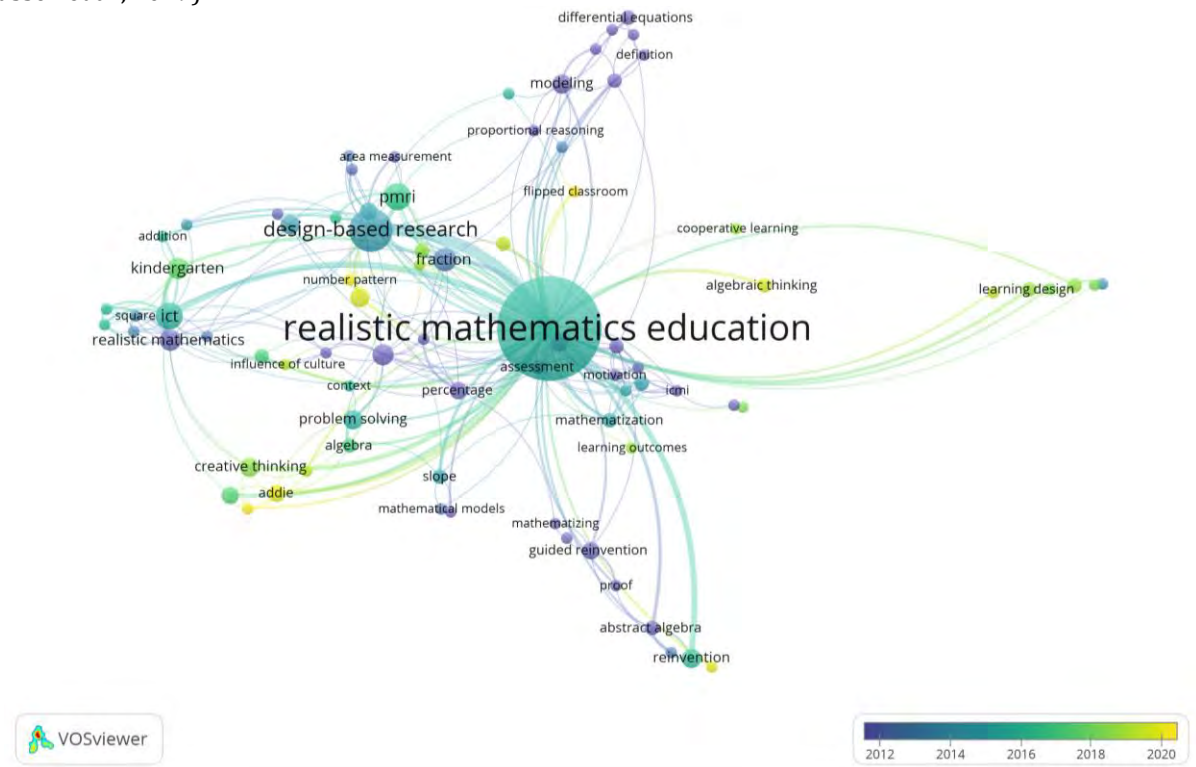

Figure 7. Science Mapping of Author's Keywords base on Co-occurrence Analysis of Author's Keywords in RME between 1972 and 2020 (Note: number of keywords: 82; number of occurrence of keywords: at least 2 times)

Discussion

RME has been regarded as an innovative teaching approach in mathematics education. Beyond the borders of the Netherlands, RME has expanded its impacts in different countries across the world. This study, to the best of our knowledge, is the first-ever review work on RME studies, using the bibliometric analysis technique. Specifically, 282 RME-related documents extracted from the Scopus database between 1972 and 2020 were analyzed, using Excel and VOSViewer. Four aspects have been investigated, corresponding with four research questions: (i) the total volume, growth trajectory, and geographic distribution; (ii) authors and research groups; (iii) sources (i.e., journal, book, conference); and (iv) the most important topics.

RME studies have been gaining traction both quantitatively and geographically in various countries around the globe, among which Indonesian publications prove to hold critical role, especially since 2017. This achievement can be explained with Indonesia's effective educational innovation policies and systematic international collaboration in curriculum research and implementation through various projects over the years, particularly the Netherlands Programme for the Institutional Strengthening of Post-Secondary Education and Training Capacity (NPT, period 2001-2003) and the project Dissemination of Pendidikan Matematika Realistik Indonesia (Do-PMRI, period 2006–2010) (Zulkardi et al., 2020). The cooperation between Dutch and Indonesian education scholars keeps thriving after these projects and results in significant activities and achievements including International RME Master's Program, International Conferences on RME, Indonesian Context-based Mathematics Contests and Mathematician Tasks Projects; RME web portal, RME Courses for South Eastern Asian secondary Math teachers; the establishment and development of

the Journal on Mathemetics Education (currently indexed in Scopus, Q2) (Zulkardi et al., 2020). In 2015, UNSRI and Utrecht University launched a new corporation program followed by the setting up of a new Doctorate Program on RME (Van den Heuvel-Panhuizen, 2020b). As a result, there has been a stable growth in the quantity of specialised and systematic RME studies by Indonesian authors since 2017 (published in Scopus-indexed journals). Indonesia would be an excellent sample for other countries with their well-structured process of ME innovation.

It can be seen that the top most cited author list is dominated by Dutch authors, who originally devised RME and whose fundamental concepts related to this issue would be referred to, cited by, examined and implemented by scientists and researchers all over the world. The co-author mapping clearly illustrates the historical cross-country collaboration in RME studies. Despite the outnumbered international networks of Dutch scholars, Indonesia proves to be an important hub for global collaboration for RME research. Obviously, the RME in Indonesia is more influenced by the Netherlands than in the US because when it comes to the United States, the RME is approached and applied with many differences compared to the Dutch way. (Webb & Frederick, 2020). This can be seen in the introduction of the new concept of 'mathematics in context'.

The findings also reveal that all the selected RME studies were published on prestigious journals in the mathematics education field. Notably, the journal with the most RME studies publications - Journal of Physics: Conference Series with 85 articles specialises in publishing conferential-related papers, which implies the keen interest among RME researchers in presentations and dissemination of RME to the world's scholar community through international conferences. The second most prolific RME journal is the Journal on Mathematics Education with 29 articles (Q2 Scopus), a Dutch - Indonesian product from RME research and implementation. The Indonesian RME scholars, thus, have successfully built up the reputation and achievements in the local scientific community as well as international influences.

Regarding the research topics, another significant keyword from the selected RME papers which co-occurred with 'realistic mathematics education' is "design-based research". This seems to point to the increasing attention to piloting and implementing the common design-based research method among these RME studies as well as the authors' interests in applying and evaluating the effectiveness of RME in Math teaching. It is completely understandable given the fact the RME is a new Dutch-originated educational approach being adapted in different countries with different cultures and educational settings.

Furthermore, it must be noted that these RME studies are fairly diverse regarding the research issues, ranging from learners' perspectives (such as creative thinking, collaborative learning, problem-solving skills, movation, mathematization, etc) to teaching contents (such as differential equations, number pattern, percentage, square, addition, etc.), teachers' perspectives and teaching activities (such as context, assessment, learning outcomes, guided reinvention, etc.). The primary school learners are found to be the dominant subjects of these RME studies compared to other educational levels. These findings offer future opportunities for further research on other math content and educational levels.

Co-occurrence analysis of the author's keywords shows no results for the combination of 'mathematics in context' and 'realistic mathematics education'. It can be seen that despite the influence of RME, the 'mathematics in context'-keyworded-studies embraced new RME interpretation and manifestations, thereby stimulating new growth of RME (Van den Heuvel-Panhuizen, 2020b) in line with local 'educational reality'.

Conclusion

For the first time, this study describes and analyzes the developments, themes and collaborations in research in the RME field. The total volume of RME-related documents and their chronological evolution indicate that RME has received increasing attention from mathematics education scholars in recent years, notably after 2016. This, indeed, reflects the increasing demand from the community for mathematicians and mathematics teachers to renovate the teaching approach in mathematics toward a more realistic way. Besides, our finding regarding the geographical distribution of RME-related documents confirmed Indonesia, the US and Netherlands as the pioneers in RME adoption. Thus, RME has been studied in 30 countries by so many authors (592 authors), not just 15 countries with 34 authors (see Van den Heuvel-Panhuizen, M. (2020a, 2020b) and especially the strong increase in research and publications of Indonesia thanks to their important national policies for mathematics education (Zulkardi et al., 2020). Although the Dutch had the most cited publications, the Indonesians have the most publications in the field of RME. RME publications can be tracked back into four different sources based on co-citation criteria, in which most of the journals are prestigious journals in the field of educational science. Design-based research and applying information technology in teaching based on RME theory are still popular research directions. This shows that RME continues to be developed and applied in many countries in the context of the Fourth technology revolution.

Recommendations

RME has become a notable research trend worldwide with a growing research community in terms of membership and geographic area. Many publications come from various countries in Europe, America, Africa, Asia, with many

differences in cultures and the development of national education. Therefore, this research provides several implications for stakeholders, including RME researchers, mathematics teachers, school managers, and educational policymakers in many countries in the world.

First, the finding regarding co-authoring patterns of scholars from these countries also draws a picture of how collaborative research in RME has evolved over the previous years. Mathematic education policymakers may use information from this finding as input to design mathematic education strategies in their own countries.

Second, our findings regarding top authors and research groups would help newcomers and junior researchers in RME studies to know their seniors to follow. Policymakers may take benefits from these findings to find the "right" scholars to consult during their policy making process.

Third, the knowledge base of RME studies identified in our findings to answer the third research question provide four main clusters of references for future RME research. Furthermore, the research gaps that have been partially pointed out in this study will be the grounds for scholars to continue to develop their own research in this topic. For example, studies on applying RME in teaching analytic knowledge or the knowledge at the lower secondary and high school levels are still in need. Cultural obstacles affecting the implementation of RME in the math classroom in Asian countries with an inherited Confucian culture can also be a promising research direction with many new contributions.

Last but not least, similar to the third implication, the keywords identified in our findings to answer the fourth research question may be worthwhile for RME scholars to identify their own research topics in the future. The results show that ICT is the top keyword in research on RME. This also reflects that ICT is being 'reality' for the social environment, in each family, in each school, and therefore a "reality" for every mathematics classroom, for each student. Therefore, future scholars may do more research on RME in the context of ICT as an important research direction, suitable for the new educational context.

Limitations

This study has several limitations, as many others do (Vuong, 2020). First, all studied documents are written in English. Meanwhile, RME studies may also be written in other languages such as Dutch, Vietnamese, Spanish, Bahasa Indonesia and especially in German (Van den Heuvel-Panhuizen, 2020b). Hence, future studies may expand the scope of study in terms of language in order to have a more comprehensive picture of RME literature.

Second, Scopus appears to exclude some important documents in RME literature, especially some important ones of Prof. Hans Freudenthal in the early days of RME's history (e.g. Freudenthal, 1968, 1973, 1991). Future studies may avoid this limitation by including a more extensive database.

The third limitation stems from the nature of the bibliometric analysis. Indeed, the bibliometric analysis only focuses on metadata information but not the contents of respective documents. Future studies may adopt other approaches such as text analysis or content analysis to avoid this research caveat.

Authorship Contribution Statement

Nguyen, Phan and Do, T. T. conceptualized the article, checked the database and contributed to writing the manuscript. All other authors collected the data, ran some data analyses and assisted in data analysis and writing.

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