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A scientometric look on mathematics education from Scopus database

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Abstract: The present work offers a characterization of the development of mathematics education, based on scientometric indicators. The study analyzes 5633 documents registered in the Scopus database which are all related to research in mathematics education. The main results show an exponential increase on the scientific productivity, a tendency to increase collaborative work over individual work, a greater impact per index of the cited references during the last two decades, a high level of international collaboration, a certain concentration of the publications on a reduced group of investigators in some international impact journals, and the existence of 17 invisible colleagues that represent scientific communities with common research interests.

Keywords: Mathematics Education, Scientometrics, Scientific Production, Invisible Colleagues

Introduction

Contemporary advances of the sciences of information have increased the interest for the study of the scientific development. In this respect, the present work focuses on the development of mathematics education, a scientific discipline that is gaining a noticeable level of organization (Biehler, Scholz, Strässer, & Winkelmann, 2002; Bikner-Ahsbahs & Vohns, 2016; Gascón, 1998; Malara, 1997; Sriraman & English, 2010).

Various terms can be found all over the world related to the teaching and learning of mathematics, which have been named in many languages as *mathematics education*, *didactics of mathematics*, *didaktik der mathematik*, *didattica della matematica*, *dydaktyka matematyki*, *didactique des mathématiques*, and *matemática educativa*. The discussion about which term is the proper one usually leads to many epistemological crossroads. However, all of them highlight the purpose of educating through mathematical instruction (Cruz, 2018).

There are many ways to explore the scientific development of mathematics education; one of which is the processing of standardized information stored in specialized databases. This information contains important metadata such as titles, authors, abstracts, keywords, cited references, sources and bibliography among others. Metadata do not substitute for the corresponding article but they bring out valuable information to give an approximate idea about its content. Standardization itself favors the statistical processing of information and the use of certain techniques to determine patterns.

Some recent works have investigated scientometric indicators related to the history of mathematics education (Bracho, Jiménez-Fanjul, Maz-Machado, Torralbo-Rodríguez, &

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Fernández-Cano, 2014). Other studies have focused on the visibility of specialized scientific journals about mathematics teaching and learning (Jiménez-Fanjul, Maz-Machado, & Bracho-López, 2013). The objective of the present work is to characterize the development of mathematics education from the perspective of its scientific productivity, using scientometric indicators.

Method

After comparing the information stored in MathEduc, ERIC, SSCI-WoS and Scopus databases, it was decided to use the last one due to the greater amount of information stored in it and because of its ease of use with automatic search. The search was developed in February 15th, 2018 by means of the following command: TITLE-ABS-KEY("mathematics education") AND PUBYEAR > n_i AND PUBYEAR <= n_{i+1}, where $\{n_i\}_{i\geq 1}$ is a succession of years, defined in such a way that each interval does not exceed 2000 documents. This last procedure was taken due to the restrictions in Scopus database for downloading CSV files with full metadata. As a result, three archives were obtained which include the following periods: 1910-2008, 2009-2013 and 2014-2018. All the information was integrated in a unique data-matrix which contains 19 standard metadata of Scopus.

The data-matrix was integrally revised to homogenize the names of some authors (for example, "Santos Trigo L.M." = "Santos-Trigo M.", "Tanisli D." = "Tanişli D.", "de Corte E." = "De Corte Erik") as well as of some keywords (for example, "Pre-service teachers" = "Preservice teachers" = "Pre-service elementary mathematics teachers" = "Preservice teacher education" = "Preservice", "K-12" = "K12" = "Mathematics K-12" = "K-12 mathematics" = "K-12 curriculum"). This standardization was important to achieve a greater objectivity in the analysis of the information. In the study, the software VOSviewer (v. 1.6.8, 2018, http://www.vosviewer.com/) was used to map several hidden relations in the metadata.

Results

The search provided a total sum of 5633 documents basically concentrated in the last 40 years. The oldest article was entitled *Accuracy in school children. Does improvement in numerical accuracy 'transfer'?* by W. H. Winch (*Journal of Educational Psychology*, 1(10), 557-589, 1910). For greater objectivity, the analysis was framed from 1978 to 2017. Figure 1 illustrates the diachronic increase of the publications in this period. It can be noticed a marked exponential increase in the prefixed interval (y = 7E-96e$^{0.1117x}$, R^2 = 0.9527). Probably, the production in 2020 will be twelve times greater than the one obtained in 2000.

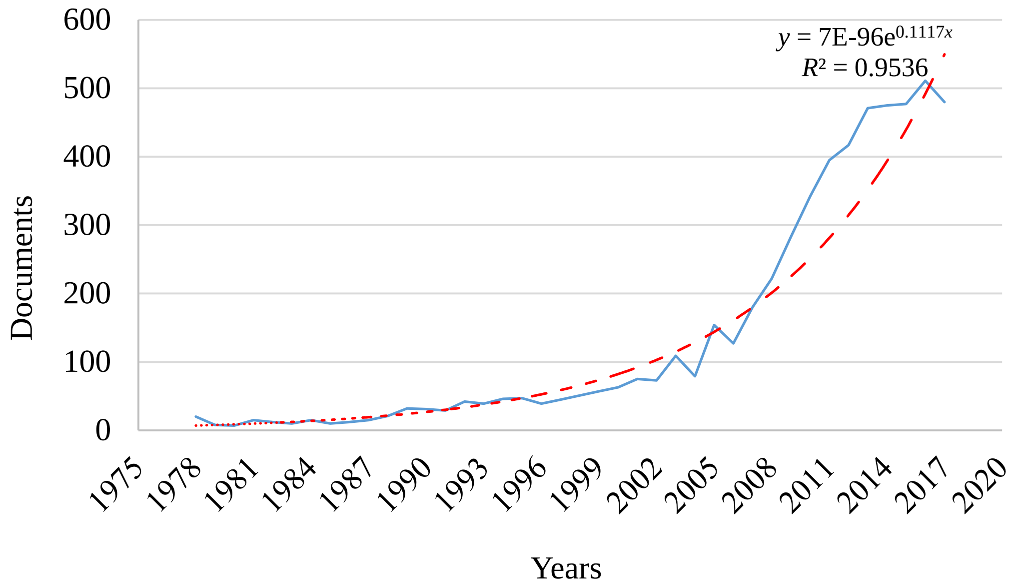

Figure 1. *Diachronic production in the period 1978-2017*

Publications were concentrated in international impact journals (66.9%), conference proceedings, and to a lesser degree in book chapters (8.7%) and books (2.4%). From the 106 countries represented in the publications, 44 have at least 10 documents and 13 at least 100. The United States is the leader by a wide margin of 1931 (34.28%). It is followed by the United Kingdom with 443 (7.86%) and Australia with 438 (7.78%). Mathematics education supposedly focuses on the development of students through instruction, so its objectives are essentially social. However, its scientific production behaves in a similar way to that of natural and exact sciences with a wide predominance of articles in relation to books. In general, social investigations confer an intrinsic value to the diffusion of knowledge through books and monographs (Bornmann, Thor, Marx, & Schier, 2016). As it can be noticed, this does not happen in the same way for mathematics education. From the scientometric point of view, this evidence suggests that mathematics education is acquiring autonomy as a scientific discipline, not necessarily subordinate to didactics, nor to sociology of education, nor to psychology of learning, among other fields to which it is closely related (Bikner-Ahsbahs & Vohns, 2016; Gascón, 1998).

Table 1 contains the distribution of documents in the different branches of science. The same document may be related to two or more fields of scientific knowledge.

Table 1. D*istribution of documents in the different branches of science*

Subject Area	Doc.	%	Subject Area	Doc.	%
Social Sciences	4588	81.45	Environmental Science	24	0.43
Mathematics	2469	43.83	Biochemistry, Genetics and Molecular Biology	23	0.41
Computer Science	633	11.24	Agricultural and Biological Sciences	20	0.36
Psychology	581	10.31	Health Professions	17	0.30
Engineering	404	7.17	Earth and Planetary Sciences	16	0.28

Arts and Humanities	299	5.31	Materials Science	15	0.27
Physics and Astronomy	120	2.13	Energy	14	0.25
Neuroscience	50	0.89	Chemical Engineering	12	0.21
Business, Management and Accounting	49	0.87	Chemistry	12	0.21
Medicine	46	0.82	Nursing	8	0.14
Economics, Econometrics and Finance	39	0.69	Pharmacology, Toxicology and Pharmaceutics	5	0.09
Decision Sciences	36	0.64	Immunology and Microbiology	4	0.07
Multidisciplinary	32	0.57	Undefined	4	0.07

Taking into account the nationality of each author and discounting 303 non-existent data, in the data-matrix 196 countries were found. The United States holds the first place with 1931 documents (34.28%), followed by the United Kingdom with 443, Australia with 438, Turkey with 319, Canada with 278, Germany with 263 and Brazil with 253. A dozen countries barely total at least 100 articles and this reduced group participates in 4574 publications. Consequently, only 6.12% of countries publishes 81.20% of the total volume.

The analysis revealed 60 authors with ten or more documents, from which 20 authors had 15 or more. The three more prolific ones were L. Verschaffel with 38, B. Sriraman with 33 and O. Skovsmose with 22. Another relevant aspect of this study consisted analyzing the existence of a tendency towards collaborative work in relation to individual publications. Figure 2 reveals that during the last 40 years, the average quantity of co-authors has increased from an individual author to three in each article.

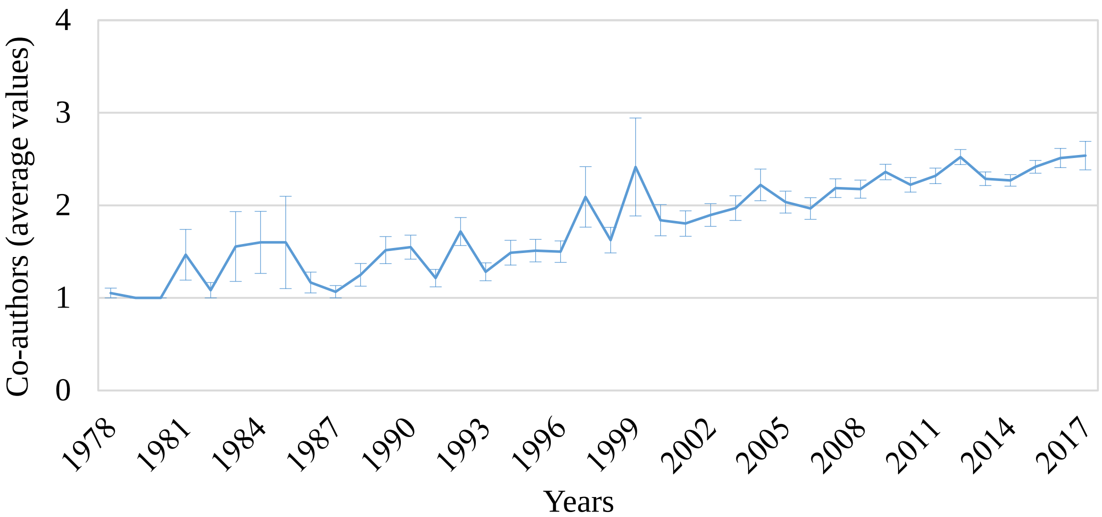

Figure 2. *Average of co-authors during the last 40 years*

There were 2905 documents (51.57%) that came from 100 institutions, mainly from universities. The three first places were occupied by: Utrecht University (Netherlands) with 68, Michigan State University (United States) with 62 and UNESP-Universidade Estadual Paulista (Brazil) with 61. On the other hand, 50 journals contained 2781 articles (49.37%) which represent almost half of the total sum of publications. Table 2 presents the 15 more productive journals in the field of mathematics education. They total 2107 documents

(37.4%). Some values that indicate their levels of impact through *SCImago Journal & Country Rank* (www.scimagojr.com) are also included.

Table 2. *Most prolific scientific journal in mathematics education*

Journal	Doc.	2016 CiteScore	2016 SJR	2016 SNIP
Educational Studies in Mathematics	370	1.35	1.228	1.788
Mathematics Education Research Journal	286	1.55	0.627	0.893
ZDM - International Journal on Mathematics Education	327	1.14	0.707	0.934
International Journal of Mathematical Education in Science and Technology	180	0.53	0.428	0.730
Bolema - Mathematics Education Bulletin	157	0.10	0.187	0.446
Journal for Research in Mathematics Education	134	1.78	2.167	1.997
Journal of Mathematical Behavior	114	0.89	0.923	1.151
International Journal of Science and Mathematics Education	96	1.32	0.893	1.212
PRIMUS	82	0.34	0.273	0.566
Procedia - Social and Behavioral Sciences	80	*	*	*
Journal of Mathematics Teacher Education	72	1.14	1.041	1.317
Eurasia Journal of Mathematics, Science and Technology Education	59	1.06	0.510	1.062
Lecture Notes in Computer Science	55	0.67	0.315	0.552
Research in Mathematics Education	50	0.87	0.918	1.007
Teaching and Teacher Education	45	3.12	1.590	2.505

(*) Information not available

Another important point is related to international research collaboration. Figure 3 contains a strong net of associations determined by VOSviewer where the size of labels is proportional to the volume of documents for each country (van Eck & Waltman, 2017). The thickness of each line of connection indicates the corresponding degree of association. Colors symbolize ten clusters with different degrees of relation.

The graph has a central and starry structure. The United States appears in the center with strong connections towards the most productive nucleus of the rest of the clusters (United Kingdom, Canada, Germany, Australia, Turkey, Israel and Brazil). A red cluster appears towards the upper-left border where Latin-American countries are concentrated (Argentina, Brazil, Chile, Colombia and Venezuela), together with other European countries such as Spain and Portugal. In general, this complex graph of collaboration shows evidence of historical, geographical and cultural links that inter-relate several countries.

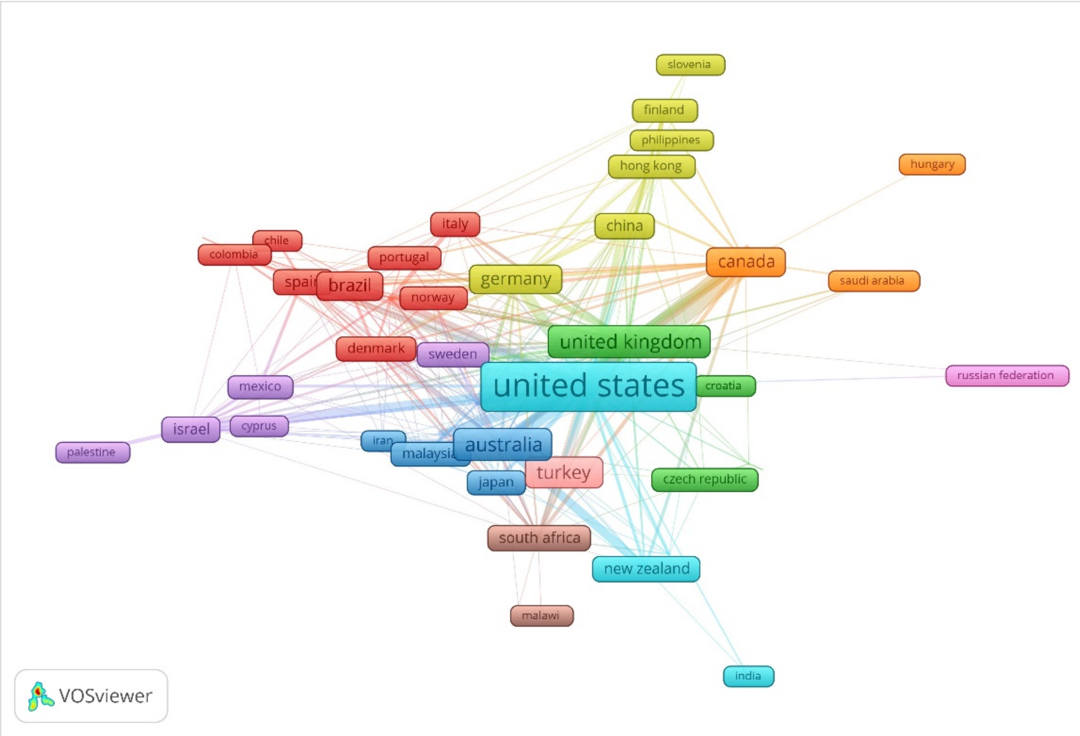

Figure 3. Links of international collaboration in mathematics education

It is significant to note the location of the Russian Federation in relation to the leading productive focus, as well as the scarce quantity of documents (ten with only one cited reference) registered in Scopus. India has a similar behavior (16 with 13 referral). It manifests strong links with Thailand. This last aspect brings about the need to incorporate other technologies of information research in future studies since Russia and India are actually countries with large populations and a significant scientific and cultural legacy. Local scientometric studies have demonstrated this assertion (Dhawan, Gupta, & Jatana, 2016; Guskov, Kosyakov, & Selivanova, 2016).

Another important aspect has to do with the impact of publications. This can be evaluated according to the number of cited references (Garfield, 1964). Figure 4 reveals that a greater number of cited references is concentrated in the decade 2003-2013 with more than 1500 mentions per year (blue color series). However, this is attributable to the high-speed and increasing volume of publications. Therefore, in order to have a clearer idea, relative values are analyzed (red color series). In this case, certain instability is observed with high local peaks in 1996 and 1999.

There are 54 authors with more than 100 cited references and 32 documents with at least 100 (five with more than 200). The most mentioned paper is *Situated learning and education* by the authors J. R. Anderson, L. M. Reder and H. A. Simon (*Educational Researcher*, 25(4), 5-11, 1996). On the other hand, 2951 documents (52.39%) have at least one citation and from them 1338 (23.75%) at least 5.

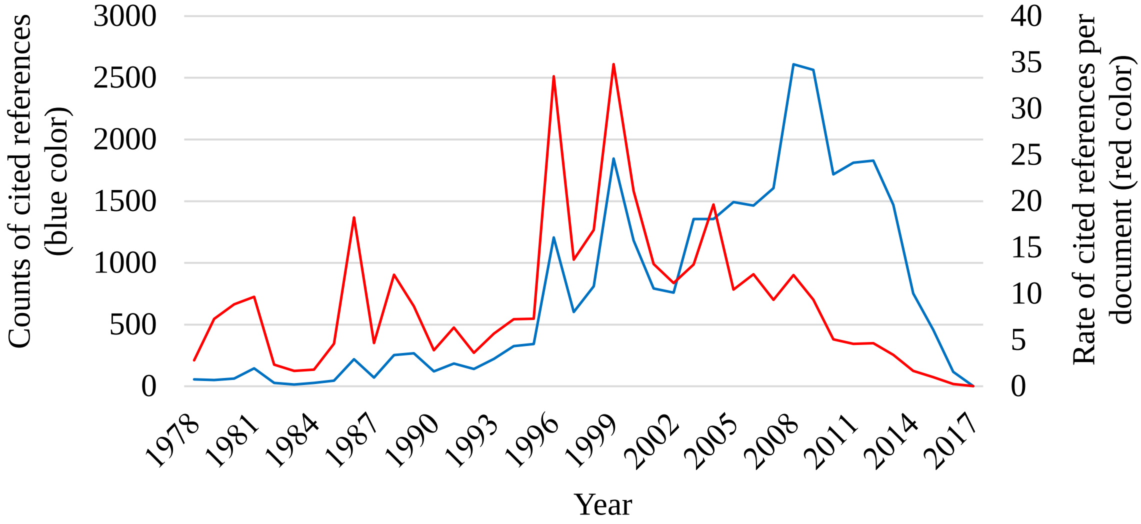

Figure 4. Absolute and relative evolution of the number of cited references

Taking into account the links of collaboration, Figure 5 illustrates 13 conglomerates that represent invisible colleges (Hattke, Vogel, & Woiwode, 2016). The scale of labels is in correspondence with the scientific leadership within each cluster, meanwhile the closeness or remoteness among the clusters indicates a greater or lesser relation, respectively. The most numerous cluster is headed by U. D'Ambrosio, with 21 investigators that share a common interest for Ethnomathematics. The cluster led by O. Skovsmose is linked to investigations in the field of critical mathematics education. The cluster headed by L. Verschaffel has as its main objective the study of mathematical word-problems based on logical-linguistic complications that hide certain elemental mathematical models. The investigations of H. P. Ginsburg are related to the formation of mathematics concepts in preschool age. The studies carried out by B. Sriraman are diverse and show an elevated versatility in the investigation of mathematics education (in cooperation with L. D. English, G. Kaiser, R. Lesh, G. Törner and as co-authors). An interesting problem for future researches is deepening focus on the subject areas of these invisible colleges, as well as the relations underlying among them.

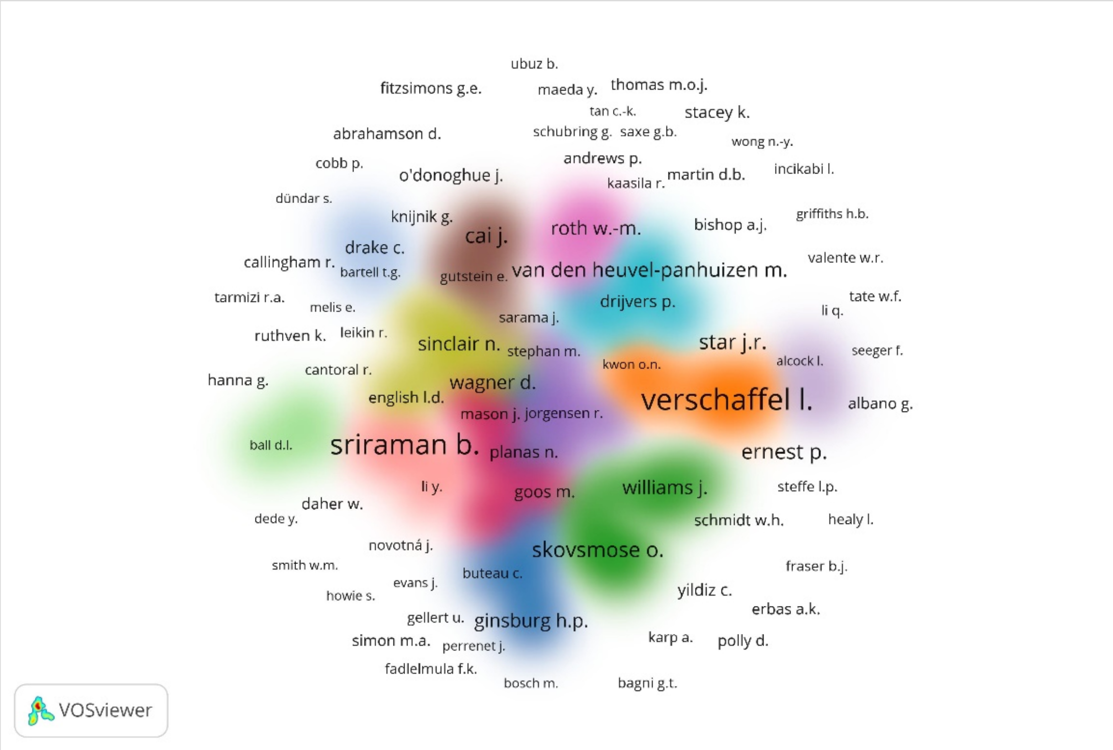

Figure 5. *Invisible colleges in mathematics education*

Conclusions

Though the information in the data-matrix is ample and comes from a reliable source, the search logic can have limitations. Through the search methods, it was not possible to determine the volume of significant data that may have been excluded. A heterogeneous perspective to analyze the problem can offer more refreshing information. Examples of this are the study of repositories of thesis related to mathematics education, and the analysis of sources coming from other databases with an international view. Another aspect that needs to be improved is the gathering of information coming from countries with high productivity and large populations, whose results are not visible in Scopus.

The results of the present study reveal that investigation in mathematics education has an exponential increase. The period of greatest impact is concentrated in the last two decades and collaborative work is privileged over individual work. Though most cited references are concentrated in a reduced group of authors, an elevated level of international cooperation is observed. Publications, as well, are concentrated in a small group of international impact journals whose levels of impact are increasing. The concentration of publications in a reduced number of authors and journals confirms, once more, the verification of Lotka's Law (Lotka, 1926) which has been determined in other investigations (Cruz & Rúa, 2018; Kumar, 2010). Lotka's law describes the frequency of publication by authors in any given field. It states that the number of authors making "x" contributions in a given period is a fraction of the number making a single contribution, following the formula $1/x^{a}$ where *a* nearly always equals two. The publication of articles is preferred in relation to books and monographs. The latter of these are necessary for the systematization of scientific knowledge (Bikner-Ahsbahs & Vohns, 2016) that is why it is necessary to increase the production of books and monographs in mathematics education.

An interesting open problem consists of the analysis of invisible colleges that have been determined. For example, it is important to look for other argumentative sources that justify their existence since the scientometric look can be limited. There are many aspects that can be studied from the structural and functional viewpoints (Hou, Retschmer, & Liu, 2008). It is also significant to study the behavior of these scientific communities, where the most remarkable problem to examine is the fundamental scope of work. This allows the analysis of research tendencies and the different contexts of the international scientific community in mathematics education (Gates & Jorgensen, 2015; Leatham, 2013).

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