Publicaciones. Facultad de Educación y Humanidades del Campus de Melilla
Depósito legal: GR-94-2001 · eISSN: 2530-9269 · pISSN: 1577-4147
Editor: Facultad de Ciencias de la Educación y del Deporte de Melilla (Universidad de Granada)

Technology-mediated mathematics learning in compulsory education: a bibliometric analysis

Aprendizaje de matemáticas mediado por tecnología en la escolaridad obligatoria: análisis bibliométrico

义务教育中以技术为媒介的数学学习：文献计量分析

Технологически опосредованное обучение математике в обязательном школьном образовании: библиометрический анализ

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Dates · Fechas

Received: 2022/01/13
Accepted: 2022/04/14
Published: 2022/10/03

How to Cite this Paper · Cómo citar este trabajo

Colomo, E., Gabarda, V., Ruiz, J., & Guillén, F. D. (2022). Technology-mediated mathematics learning in compulsory education: a bibliometric analysis. *Publicaciones, 52*(1), 35–55. https://doi.org/10.30827/publicaciones.v52i1.22298

Abstract

Introduction: The integration of technology in educational processes has been consolidated as a reality in any context, at any stage and in any subject. This integration, beyond being linked to the inclusion of specific content and the recognition of digital competence as a basic skill, is linked to the consideration of technology as a tool at the service of learning, associated with its potential as a methodological resource.

Method: Under this consideration, this paper analyses, from a bibliometric perspective, the scientific production on the use of technology as a tool for learning mathematics in compulsory schooling in the Scopus database. The sample is made up of 132 articles published between 2015 and 2021, to which different bibliometric techniques (bibliographic coupling, co-citation and co-occurrence) are applied.

Results: The results show an upward trend in scientific production on the phenomenon under study, with higher indexation in the areas of social sciences and computer science. Although most of the publications are in English-language journals, most of the research is contextualised in Spain, followed by the United States. The co-occurrence identifies Secondary Education as the main context, although there is also a notable presence of Primary Education, with the presence of different methodological proposals. Finally, there is a notable impact (in terms of number of citations) of the publications linked to the topic of study.

Conclusions: Thus, we conclude the relevance of technology-mediated mathematics learning in compulsory schooling, outlining an area of study of priority projection in the coming years.

Keywords: bibliometric study, mathematics, educational technology, compulsory education.

Resumen

Introducción: La integración de la tecnología en los procesos formativos se ha ido consolidando como una realidad en cualquier contexto, etapa y materia. Esta integración, más allá de vincularse a la inclusión de contenidos específicos y al reconocimiento de la competencia digital como una destreza básica, se vincula con la consideración de la tecnología como una herramienta al servicio del aprendizaje, asociada a su potencial como recurso metodológico.

Método: Bajo esta consideración, este trabajo analiza, desde una perspectiva bibliométrica, la producción científica sobre el uso de la tecnología como herramienta para el aprendizaje de las matemáticas en la escolarización obligatoria en la base de datos Scopus. La muestra está conformada por 132 artículos publicados entre 2015 y 2021, a los que se aplican diferentes técnicas bibliométricas (acoplamiento bibliográfico, co-citación y co-ocurrencia).

Resultados: Los resultados muestran una tendencia al alza de la producción científica sobre el fenómeno de estudio, con mayor indexación en las áreas de ciencias sociales y ciencias de la computación. Aunque las publicaciones se encuentran de manera mayoritaria en revistas anglófonas, la mayor parte de las investigaciones están contextualizadas en España, seguidas de las realizadas en Estados Unidos. La co-ocurrencia identifica la Educación Secundaria como contexto mayoritario, aunque hay una presencia notable también de la Educación Primaria, habiendo presencia de diferentes propuestas metodológicas. Destaca, por último, una repercusión notable (en número de citas) de las publicaciones vinculadas al tema de estudio.

Conclusiones: Se concluye, de este modo, la relevancia del aprendizaje de las matemáticas mediado por tecnología en la escolaridad obligatoria, dibujando una línea de acción prioritaria en los próximos años.

Palabras clave: análisis bibliométrico, matemáticas, tecnología educativa, escolaridad obligatoria.

摘要

引言：技术在培训过程中的整合在任何背景、阶段和主题中都已成为现实。这种整合，除了与包含特定内容和承认数字能力作为一项基本技能相关之外，还与将技术视为服务于学习的工具以及其作为方法资源的潜力相关联。

研究方法：在此考虑下，本研究从文献计量学的角度分析了Scopus数据库中使用技术作为义务教育数学学习工具的科学产出。该样本由 2015 年至 2021 年间发表的 132 篇文章组成，其中应用了不同的文献计量技术（书目耦合、共引分析和共现分析）。

研究结果：结果显示，所研究现象的科学产出呈上升趋势，在社会科学和计算机科学领域的索引度更高。尽管大多数出版物都出现在英语期刊上，但大多数研究都是在西班牙进行的，其次是在美国进行的。同现分析将中学教育确定为主要背景，尽管小学教育也有显着存在，但存在不同的方法建议。最后，与研究主题相关的出版物有显着影响（引用次数）。

结论：综上所述，我们总结了以技术为中介的数学学习在义务教育中的相关性，概述了未来几年优先预测的研究领域。

关键词：文献计量分析，数学，教育技术，义务教育。

Резюме

Введение: Интеграция технологий в образовательные процессы становится реальностью в любом контексте, на любом этапе и в любом предмете. Эта интеграция, помимо включения конкретного содержания и признания цифровой компетентности в качестве базового навыка, связана с рассмотрением технологии как инструмента на службе обучения, связанного с ее потенциалом в качестве методологического ресурса.

Метод: В соответствии с этим соображением в данной статье проводится библиометрический анализ научной продукции по использованию технологии как инструмента для изучения математики в обязательном школьном образовании в базе данных Scopus. Выборка состоит из 132 статей, опубликованных в период с 2015 по 2021 год, к которым были применены различные библиометрические методы (библиографическая связь, совместное цитирование и совпадение).

Результаты: Результаты показывают тенденцию к росту научной продукции по изучаемому явлению, с более высокой индексацией в областях социальных наук и информатики. Хотя большинство публикаций публикуется в англоязычных журналах, большинство исследований посвящено Испании, затем следуют исследования, проведенные в США. Совместное использование определяет среднее образование как основной контекст, хотя также заметно присутствие начального образования, с наличием различных методологических предложений. Наконец, выделяется заметное влияние (по количеству цитирований) публикаций, связанных с темой исследования.

Выводы: Таким образом, делается вывод об актуальности технологически опосредованного обучения математике в обязательном школьном образовании.

Ключевые слова: библиометрический анализ, математика, образовательные технологии, обязательное школьное образование.

Introduction

During the past two decades, technology has gained more and more importance in the development of our daily life. Indeed, technology has an influence on many of our day-to-day activities in the different areas of our life (academic, professional, social, and personal), and has become a key element when performing different tasks both at work and in the educational environment, including communication, socialisation, and the creation of interpersonal relationships.

In the educational sphere, digitisation has been taking different shapes. At a physical level, schools have progressively transformed their rooms to house devices and software which are used in teaching and learning. Thus, desktop and laptop computers, projectors, digital whiteboards, and tablets are a tangible reality in most schools around the world. Furthermore, technology has been integrated into the curriculum, either as a separate subject area or as a cross-cutting topic to be addressed within other subject areas. This reality explains the political and institutional interest in ensuring that students, at different educational stages, develop specific skills. Also linked to this issue, on a supranational level, digital competence is recognised as a skill that citizens need to develop throughout their life. Therefore, beyond the formal educational sphere, the idea is that people ought to have a series of skills that enable them to develop in an appropriate way in the hyper-connected society in which we live.

These three issues have influenced in different ways the phenomenon analysed in this study proposal: technology-mediated mathematics learning in compulsory education. First of all, focusing on the more global to the more specific aspects, it is worth starting from the EU guidelines which have identified the key competences that people should have. The point of reference is here the Community guidelines proposed by the Commission and the European Council in 2006, and revised in 2018, which explicitly showed the two main key points of our proposal. On the one hand, mathematics has traditionally been an area of knowledge in the academic curriculum, with a historical presence in different educational contexts and stages. This relevance is reflected in EU documents, which identify mathematical competence in synergy with science, technology, and engineering skills. Specifically, mathematical ability is described as the skill to deploy and employ mathematical reasoning to solve problems in everyday life, specifically in calculation, logical, and spatial thinking and representation (formulas, graphs, etc.). Moreover, technology and engineering related skills are geared towards the application of this knowledge to everyday life, as an individual and as a citizen. Furthermore, and apart from these proposals, digital competence is seen as another of the skills for lifelong learning and it is considered a skill in its own right. This is related to instrumental and literacy issues (communication, content creation, participation, problem solving, etc.), but also to other attitudinal matters, where the safe and critical use of technologies, digital well-being, and cybersecurity are key.

This reality is framed within a general context that acknowledges not only the relevance of technology for the development of the individual and of society, but also the need for every citizen to be competent in both mathematical and technological areas. Moreover, this framework has been used as a reference for education systems in different countries to shape their curricula at different educational stages. This is why mathematics is a compulsory subject in compulsory schooling (primary and secondary education), while technology is usually taught in a cross-curricular way in primary education, while in secondary education it has a dual function: it can either be still a cross-curricular subject integrated into the rest of the subjects; or it is taught as a subject in its own right.

Furthermore, beyond the strictly curricular sphere, the two areas analysed in this paper (mathematics and technology) are linked by a methodology that is on the rise: STEM (Science, Technology, Engineering & Mathematics). This focuses on learning scientific disciplines through active methodologies and with a practical purpose, and thus fulfilling social demands (Arabit & Prendes, 2020). Mathematics plays a fundamental role in this methodology, as it is considered the foundation for the development of the other areas (Maass et al., 2019).

Given that the integration of technology in mathematics is given consideration within the curriculum, there is another issue that clearly affects its feasibility: the availability of equipment and digital resources (devices, software, and any other type of technological tool). In this regard, it should be noted that technology can be implemented in different formats, providing different possibilities for the implementation of mediated learning processes. Thus, there is general technology (which is not directly aimed at learning mathematics) that is used for this purpose, but there are also specific tools that have been designed ad hoc for this purpose. In the first case, some studies support the use of augmented reality (Jesionkowska et al., 2020; Petrov & Atanasova, 2020), which has shown remarkable potential, for example, for the understanding of conceptual issues, motivation, autonomous learning, research skills, and socialisation, aspects that are also enhanced by the use of robotics (Aris & Orcos, 2019). Also, the use of virtual reality (Buentello-Montoya et al., 2021), as well as immersive virtual reality (Menjivar et al., 2021; Silva-Díaz et al., 2021), helps improve attitudes towards mathematics, while the use of generic tools such as YouTube, search engines, blogs, forums, and instant messaging in training activities related to mathematics (García-Martín & Cantón-Mayo, 2019; Gil-Quintana et al, 2021; Juárez et al., 2020) can improve academic performance, as well as on the interaction and the level of learning developed in terms of mathematical thinking. Also not to be ignored are video games and gamification as methodological resources, given their increased integration into educational processes in any area and at any level. Studies such as Curto et al. (2019) and Umboh et al. (2021) evaluate the use of Kahoot, concluding that it promotes the development of skills such as self-regulation of individual and autonomous work as well as the achievement of the academic objectives. Other authors show the usefulness of simulators (Díaz, 2018) for improving academic performance in mathematics. Likewise, studies such as those by Kim and Fe (2017), Molina et al. (2020) and Pellas et al. (2021) conclude that, generically, these recreational resources contribute to more meaningful learning and have a direct impact on the improvement of arithmetic problem solving.

Besides, when focusing on technologies designed ad hoc for learning mathematics, other generic proposals also support their potential for improving academic performance (Martínez-Garrido, 2018) and for meaningful learning (Zeynivandnezhad et al., 2020). In terms of specific resources, the use of Geogebra (Del Cerro, & Morales, 2021; Weinhandl et al., 2021), a tool on which much of the scientific literature on this study phenomenon is based, stands out above the rest. Authors such as Alabdulaziz et al. (2021), Birgin and Acar (2020) and Zulniadi et al., (2019) found its use improves mathematical skills at different educational stages, as well as academic performance. Moreover, García et al. (2020), among others, stated that it is also beneficial for the improvement of interpersonal relations.

Furthermore, other studies such as Rodríguez-Cubillo et al. (2021) and Kristianti et al. (2017) highlight the existence of other resources beside Geogebra, such as mobile applications designed specifically for mathematics, which help improve attitudes towards this academic area, foster motivation and the development of critical thinking.

This analysis leads to the conclusion that, regardless of how the technology is employed, scientific literature does seem to confirm that it is widely used in mathematics learning (Gómez-García et al., 2020), especially after the COVID-19 pandemic (Hossein-Mohand et al., 2021; Iglesias et al., 2020).

Thus, the aim of this study is a bibliometric analysis of the scientific production of technology-mediated mathematics learning in compulsory education, hosted in the international database Scopus.

Based on these premises, the following research questions will be answered:

1. Considering the variables year of publication, area of indexation, journals, country, and most cited publications, what are the characteristics of the scientific production under study?
2. What are the main lines of research related to field of study?
3. Who are the authors with the most influential publications in academia?

Methodology

This study is a bibliometric analysis aimed at identifying the research on the learning of mathematics through technology in compulsory education. This technique is based on a meta-analysis of scientific production (González et al., 2020) and its evolution considering some pre-established criteria. These criteria, of a quantitative and descriptive nature, highlight issues such as the area of knowledge in which the publications are indexed, the year in which they are published and the authorship. This technique has been validated by research that supports its usefulness and efficacy (Colomo et al., 2020; Ros-Garrido & Chisvert-Tarazona, 2018).

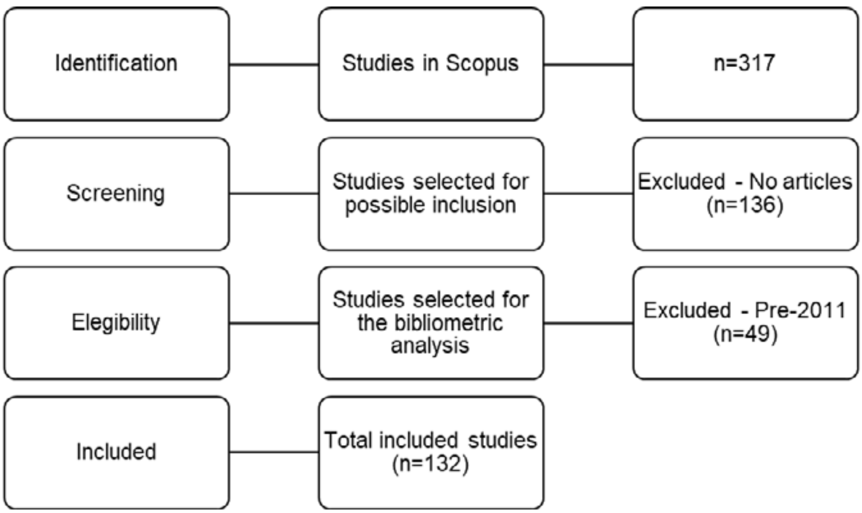
Considering the fact that there are variations in the way each database covers scientific fields and journals (Aria & Cuccurullo, 2017), and that the choice is therefore not neutral (Waltman, 2016), the search for publications has been carried out using the international database Scopus. For this study, the potential sample consisted of only a small the number of papers due to the limited use of technologies within the subject of mathematics in the various stages of compulsory education, together with the parameters and filters that needed to be applied to the search. Considering this, only the Scopus database was used as it is recognised as a tool of academic quality because of its comprehensiveness and academic criteria (Caviggioli & Ughetto 2019). Scopus' scientific production is also subject to rigorous quality criteria, which is a relevant reason for its exclusive use (Khanra et al., 2020); it is also better, compared to Web of Science, in terms of finding descriptors of more specific scientific fields (Rodríguez-Sabiote et al., 2020), as in the case of this study. In addition, a decision was made not to use other databases simultaneously as most of the papers were duplicates or incorporated research published in journals that did not meet the requirements and quality criteria of the most prestigious international databases.

The descriptors and Booleans used for the search command were “mathematics” OR “maths” AND “learning” AND “primary education” OR “secondary education” OR “compulsory education” OR “obligatory education” AND “technology” OR “ICT”. This search was carried out in the title, keywords, and abstracts, yielding a total of 317 documents up to 27 September 2021; the publications included papers, book chapters, and conferences, among others.

Different screening criteria were applied on the 317 resulting documents, according to the object of study and following the PRISMA statement (Figure 1). Initially, the type of publications was restricted to papers only, omitting documents referring to books, book chapters, reviews or conferences. This narrowed the sample to 181 documents. In addition, only papers published between 2015 to the present day (i.e., 7 years) were included, omitting those published prior to that. The final product, after applying the different filters and restrictions, was 132 papers (120 in English, 9 in Spanish, 1 in Portuguese, 1 in Chinese, and 1 in Turkish). This was exported from Scopus in comma separated values (.csv) for subsequent bibliometric analysis.

Figure 1

Phases of the publication selection process based on the PRISMA declaration



Different bibliometric techniques were applied: firstly, the scientific production was analysed in order to study the trend of the publications according to variables such as the year of publication, the area of indexation, the periodicity, the country, and the number of citations. Then, bibliometric analyses were applied while maintaining the conceptual, intellectual, and social structure (Aria & Cuccurullo, 2017). The conceptual structure was elaborated through a co-occurrence analysis, where, by examining the set of words, it was possible to identify the key descriptors or keywords that make up the contents of the proposals analysed. The intellectual structure was examined by co-citation analysis, which reveals the frequency with which different papers are co-cited. Finally, the social structure was obtained by applying the technique of bibliographic coupling, which allows to determine the impact of a publication in the scientific field according to its similarity (shared references) with other studies on the same subject.

The VOSviewer software was used to investigate the relationships between the papers of the sample. This software allows a visual representation of the existing relational nodes according to the factor examined, and it is especially useful for displaying large bibliometric maps (Aria & Cuccurullo, 2017).

In terms of the analysis of the scientific production, the following types of variables were included: year of publication, to assess the evolution of scientific production over time; indexing areas, to determine to which subject areas the papers belong; periodicals, to identify the journals that published the most papers on the field of study; country, to find out which countries have given more importance to research on mathematics learning in compulsory education; most cited publications, to identify the publications with the most impact in this field. To this end, the inclusion/exclusion criteria are set out for each of the variables mentioned in order to carry out the analysis of the scientific production (Table 1).

Table 1

Analysis variables and inclusion/exclusion criteria

Variables	Inclusion/exclusion criteria
Year of publication	All publications between 2015 and 2021
Indexation areas	All areas with minimum 12 publications
Periodicals	All journals with minimum 4 publications
Country	All countries with minimum 6 publications
Most cited publications	All publications with minimum 38 citations

Results

In order to specifically address the objectives of this paper, the results presented below are structured according to the bibliometric techniques used to answer the research questions. Thus, the analysis is firstly carried out on the scientific production, then the results of bibliographic coupling and, finally, on co-citation and co-occurrence.

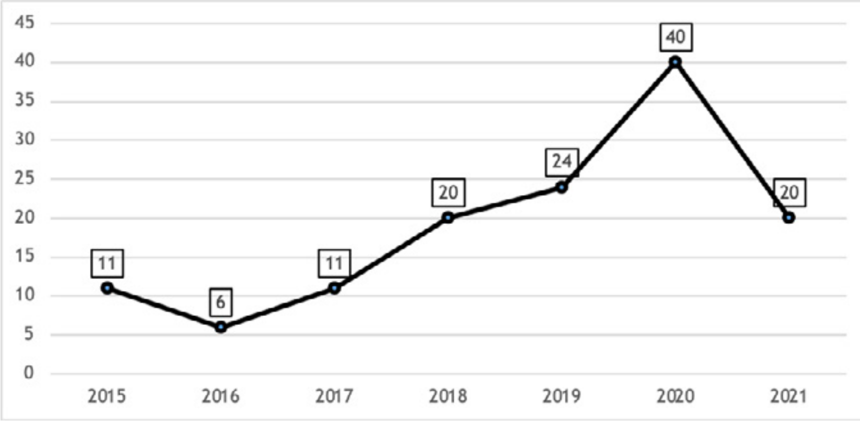
Analysis of the Scientific Production

Taking the 132 papers that make up the study sample as a starting point, the analysis of the different study variables proposed above is presented below.

As for the year of publication, the time range of this study is from 2015 to 2021. During this time, scientific production has followed an upward trend, with 11 papers in the first year and 20 in the last. During this period, except for a drop in publications in 2016 (with only 6), there has been a steady increase in papers, with 11 in 2017, 20 in 2018, 24 in 2019 and a peak of 40 in 2020. In the last year analysed (2021), 20 papers were found, which is understandable considering that the analysis did not include the entire year.

Figure 2

Papers per year of publication



With regard to indexation, the inclusion criterion for this variable, as noted above, is set at a minimum of 12 publications. It should also be pointed out that a publication may be assigned to more than one area of knowledge (multi-classification criterion) and included in several of them. It is for this reason that total amount of papers in the different areas is higher than the 132 publications analysed (Table 2).

Table 2

Indexation areas

Area	Number of publications
Social Sciences	108
Computer Science	46
Engineering	18
Psychology	18
Mathematics	12

The area with the highest number of proposals was social sciences (108), accounting for most of the allocation. Secondly, the papers are in the area of computer science (46), followed by engineering (18) and psychology (18), and finally in mathematics (12). This distribution responds to two fundamental questions: on the one hand, many of the papers focus on didactic proposals that analyse the impact of different methodologies on the learning of mathematics. This offers a response to the more pedagogical area of knowledge and, therefore, of social and, in part, psychological knowledge. On the other hand, the association to technological areas (computing and engineering) means that emphasis is put on the use of technology for learning and, therefore, the use of equipment, software, and other digital resources. It is curious, however, that the affiliation to the mathematical area is residual, considering that all the proposals are linked to this area of knowledge.

In any case, looking at periodicals and considering the exclusion criterion of a minimum of 4 papers related to the subject (Table 3), there are five journals that meet this criterion, all of them in English. The journal *Computers and Education* of the Elsevier Group (UK) stands out with 15 publications, followed by two journals of the Swiss MDPI group (*Education Sciences* and *Sustainability*), with 8 and 7 publications respectively. The *International Journal of Technology and Design Education* (by the Springer Group) and *Mathematics* (again by MDPI) are at the bottom of the list with 4 publications.

Table 3

Most prolific journals indexed in Scopus on the subject under study

Name of the journal	Number of publications
Computers and Education	15
Education Sciences	8
Sustainability	7
International Journal of Technology and Design Education	4
Mathematics	4

In terms of the country, there are a total of six countries that meet the inclusion criterion, with 6 or more publications on the subject under study (Table 4). As can be observed, there is a predominance of papers whose authors are affiliated with institutions located in Spain (43 in total), followed by the United States with 21 entries.

Table 4

Countries with the highest scientific production in Scopus

Country	Number of publications
Spain	43
United States	21
Australia	8
Turkey	8
UK	7
Greece	6

Finally, with regard to the most cited publications, the analysis of the impact and the relevance of the publications according to the number of citations is subject to the criterion of a minimum of 38 total citations (Table 5).

Table 5

Most cited papers in Scopus

Authors	Year	Title	Journal	Citations	Average number of citations per year
Lo, C.K., Lie, C.W., Hew, K.F.	2018	Applying "First Principles of Instruction" as a design theory of the flipped classroom: Findings from a collective study of four secondary school subjects	*Computers and Education* 118, 150-165	56	14
Bray, A., Tangney, B.	2017	Technology usage in mathematics education research – A systematic review of recent trends	*Computers and Education* 114, 255-273	50	10
Dorouka, P., Papadakis, S., Kalogiannakis, M.	2020	Tablets and apps for promoting robotics, mathematics, STEM education and literacy in early childhood education	*International Journal of Mobile Learning and Organisation* 14(2), 255-274	44	22
Sinclair, N., Bartolini Bussi, M.G., de Villiers, M., (...), Leung, A., Owens, K.	2016	Recent research on geometry education: an ICME-13 survey team report	*ZDM - Mathematics Education* 48(5), 691-719	40	6.7
Nadelson, L.S., McGuire, S.P., Davis, K.A., (...), Nagarajan, R., Wang, S.	2017	Am I a STEM professional? Documenting STEM student professional identity development	*Studies in Higher Education* 42(4), 701-720	38	7.6
Cascales-Martínez, A., Martínez-Segura, M.-J., Pérez-López, D., Contero, M.	2017	Using an augmented reality enhanced tabletop system to promote learning of mathematics: A case study with students with special educational needs	*Eurasia Journal of Mathematics, Science and Technology Education* 13(2), 355-380	38	7.6

First of all, it is worth noting that among the papers that meet this criterion, there are publications from 2016 to 2020; however, the year of publication is not an unequivocal response variable for higher citation. Likewise, international authorship stands out under this criterion, with only one paper by a Spanish author among the most cited. Furthermore, all the proposals with the highest impact are published in international journals, with *Computers and Education* being the one that stands out for having published the two papers with the highest impact (106 citations between the two).

The most cited paper (56 in total and 14 per year on average) is by Lo et al. (2018) followed by the one by Bray and Tangney (2017), with a total of 50 citations and an average of 10 citations per year. The paper in the third place (Dorouka et al., 2020) was published in 2020, but has already reached a total of 44 citations and an average of 22 per year, which is an outstanding result. The results are rounded off by the works by Sinclair et al. (2016) with 40 total citations and an average of 6.7 per year, and the publications by Nadelson et al. (2017) and by Arregle et al. (2017) both with 38 total citations and an average of 7.6 per year.

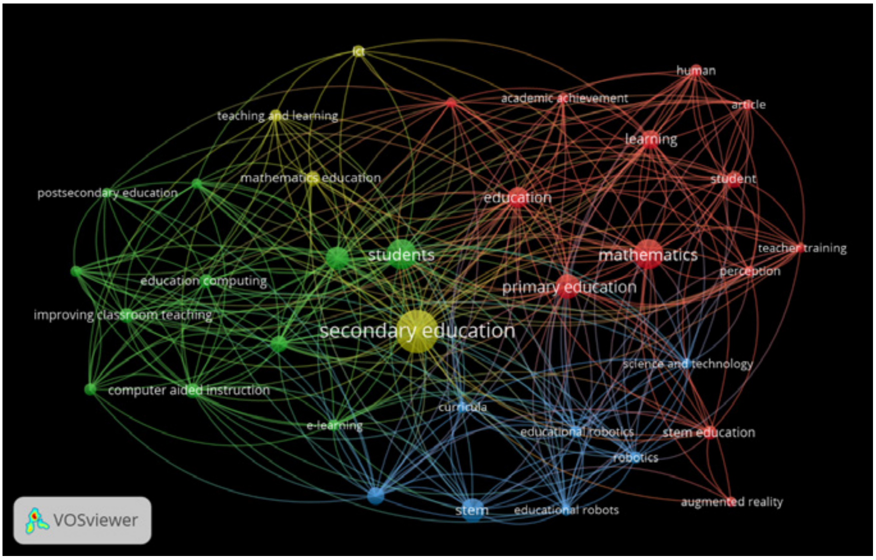
Conceptual structure: co-occurrence analysis

The conceptual structure makes it possible to examine the main lines of research of a subject by using keyword co-occurrence analysis as the bibliometric technique. This analysis helps to identify the core descriptors of the publications. In this way, the frequency of sets of words yields information about their conceptual linkage. This analysis makes it possible to identify the lines of research linked to technology-mediated mathematics learning in compulsory education.

By analysing the co-occurrence of descriptors, out of the 132 papers in the study sample, the authors suggested 456 keywords and the papers were indexed with 436 keywords, reaching a total of 802. Of these, 35 keywords appeared more than 5 times in the papers under study (Figure 3). Four co-occurrence clusters were generated, determined by the relationships between the descriptors used as keywords.

Figure 3

Concurrence of keywords in scientific production



The terms with the highest concurrence were s*econdary education* (47) and *mathematics* (27), matching the search descriptors, together with s*tudents* (27), which is the keyword with the highest concurrence intensity (total link strength 133). The key word STEM is also worth highlighting (31 concurrences when the acronyms are grouped together with the descriptor of the terms the word consists of), as a pedagogical approach to global and holistic learning of science. Other descriptors, such as *e-learning* (7), *robotics* (7) and *augmented reality* (5), reflect different strategies and methodologies to approach mathematics learning through technology.

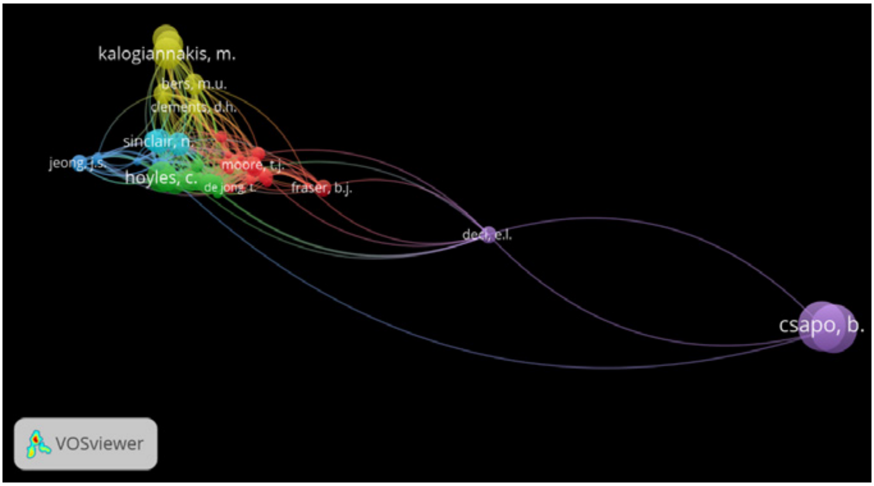
Intellectual Structure: Co-citation Analysis

The intellectual structure helps identify the knowledge base of a subject by applying co-citation analysis. This makes it possible to identify the subjects linked to the existing literature on a particular topic. This analysis complements the co-occurrence analysis, so that the papers cited together provide information on thematic areas of research.

In terms of co-citation, the criterion for the analysis was to have 10 or more citations, which was met by 52 items (Figure 4). As a result, 6 co-citation clusters were generated from co-cited papers. It is worth mentioning the co-citation intensity in the papers by Csapo (total link strength 871), Molnar (total link strength 876) (Csapó & Molnár, 2019), and Hoyles (total link strength 440) (Hoyles, 2018), as these are the authors ranking second, third and fourth in terms of citations (33, 26, and 23, respectively). The most cited author is Fraser (Koul et al., 2018), with a lower co-citation intensity (total link strength 180).

Figure 4

Co-citación, unit of analysis "authors"



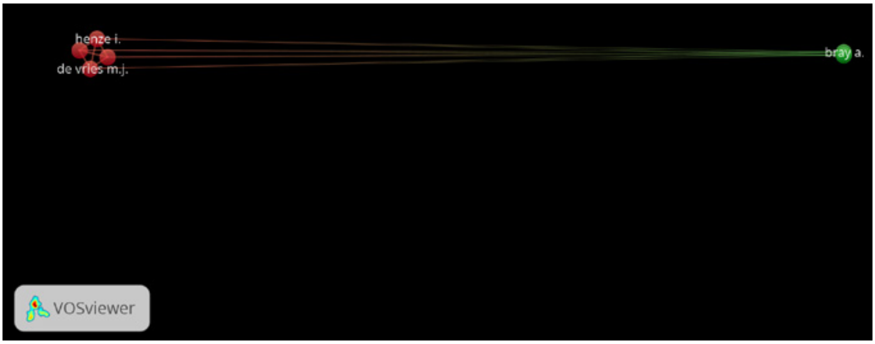
Social Structure: Analysis of Bibliographic Coupling

By using the bibliographic coupling technique, the social structure makes it possible to know who the main authors are and their relationships within a thematic community. This analysis allows to identify the influence of a paper on the overall scientific output under study. Specifically, the relationship and similarity with the rest of the publications is analysed by looking at the number of references that the publications under study have in common and establishing a backward citation chain. This technique allows to identify the authors who can be regarded as referents in the phenomenon under study. Thus, the authors are used as the unit of analysis for the bibliographic coupling, by setting as inclusion criterion at least 2 papers and 8 citations per author, which was met by 10 items. Figure 5 reflects the resulting relational nodes.

Two sets of authorships were established based on their coupling relationship. It is worth highlighting the intensity of the coupling (total link strength 532) generated between the papers by authors belonging to the red cluster (Vossen et al., 2018, 2020a, 2020b), even though they are not the most cited papers. In contrast, the green cluster (Bray & Tangney, 2016, 2017) has lower intensity (coupling) although they share the most citations (79).

Figure 5

Bibliographic coupling, unit of analysis "authors"



Discussion and Conclusions

A bibliometric analysis of the scientific literature on technology-enhanced mathematics learning in compulsory education has shown that this is a growing phenomenon at international level. Considering the results, it is relevant to point out that journals written in English are the most important ones, regardless of the authors' geographical context and the countries where the research is carried out.

Thus, at a general level, scientific production has grown progressively over the past five years (pending complete data for 2021), with social sciences and computer sciences as the predominant areas of indexation. It is precisely the most prolific journal in terms of publications and citations (*Computers and Education*) which is an example of synergy between these areas of knowledge, and it has become a point of reference on the use of technology as a tool for learning mathematics in primary and secondary education. It is precisely the papers with the highest number of citations that analyse this issue, highlighting the potential of possibilities such as the flipped classroom (Lo et al., 2018), robotics (Dorouka et al., 2020), augmented reality (Cascales-Martínez et al., 2017) or other trends (Bray & Tangney, 2017) in training processes in this field, as well as in the development of professional identity (Nadelson et al., 2017).

In terms of the main lines of research linked to the field of study, most research focuses on the use of technology as a means of improving mathematics learning (Benton et al., 2018; Bray & Tangney, 2017; Hoyles, 2018; Larkin & Calder, 2016; Papadakis et al., 2016), with research on teachers and the factors that affect this praxis being key (McCulloch et al., 2018). Alongside these, attention must be paid to the works that focus specifically on mathematics (Benton et al., 2017; Leroy & Bresoux, 2016), meaning that proposals for improvement using technologies are the result of knowing the magnitude and reality of the problem with this subject. Linked to this, there are multiple references to research on STEM as a way of addressing the mathematical knowledge domain, integrating mathematics and technology, science and engineering (Dasgupta et al., 2019; Dorouka et al., 2020; Nadelson et al., 2017; Psycharis, 2018). Finally, it is worth highlighting the research that focuses on specific tools or methodologies for learning mathematics through technology, such as the use of the Flipped Classroom (Adams & Dove, 2016; Bhagat et al, 2016; Clark, 2015; Kirvan et al., 2015); augmented reality (Cascales-Martínez et al., 2017; Demitriadou et al., 2020); and the impact of the use of iPads (Harrison & Lee, 2018) and tablets (Schacter & Jo, 2017) when learning mathematics.

In terms of the authorship of the most influential papers in the sample, the work of Bray and Tangney (2016, 2017) should be pointed out, as they focus on the use of technology as a means for learning mathematics. In this respect, the 2017 paper is one of the most cited (in 2nd place). Also relevant are the works by Vossen et al. (2018, 2020a, 2020b), which focus mainly on the STEM method, addressing knowledge development, attitudes, and perceptions of both students and teachers.

One of the limitations and also line of future work, is the inclusion of a single database for the bibliometric study (Scopus), with the possibility to extend the study with other resources such as ERIC or Web of Science. This will allow a more global vision of the topic analysed, although as mentioned in the methods section, the characteristics of this search meant that only Scopus was used in this case. Another option to be considered is to use Biblioshiny as a tool for bibliometric analyses, given that it allows the inclusion of statistical tests with R.

In addition, it would be useful to analyse the literature prior to 2015, as well as the whole year 2021, with the possibility to highlight both the projection of the scientific literature and the evolution of technology as a tool at the service of learning mathematics.

In line with this last point, a systematic review of the literature focusing on the papers in this study could contribute to deepening and materialising the specific tools that are being implemented in education that are linked to the teaching and learning of mathematics, as well as the specific impact they have on training processes.

Financing

This paper is part of the Erasmus + IMAS (Increasing Mathematical Attainment in Schools) project, reference 2019-1-ES01-KA201-065104 (2019-2022), funded by the European Union.

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