sustainability

Review

Co-Word Analysis and Academic Performance of the Term TPACK in Web of Science

Rebeca Soler-Costa [1], Antonio-José Moreno-Guerrero [2], Jesús López-Belmonte [2,*] and José-Antonio Marín-Marín [3]

[1] Department of Educational Sciences, University of Zaragoza, 50009 Zaragoza, Spain; rsoler@unizar.es
[2] Department of Didactics and School Organization, University of Granada, 51001 Ceuta, Spain; ajmoreno@ugr.es
[3] Department of Didactics and School Organization, University of Granada, 18071 Granada, Spain; jmarin@ugr.es
* Correspondence: jesuslopez@ugr.es

Abstract: The progress of technology has led to the emergence of new teaching methods, among which Technological Pedagogical Content Knowledge (TPACK) can be found in an attempt to promote the integration of technology and knowledge, combining technology, pedagogy and theoretical content. The aim of this research is to analyze the significance and evolution of the TPACK concept in the publications contained in Web of Science (WoS). The research method chosen is based on bibliometrics, specifically on the analysis of academic performance and on the analysis of co-words. The total number of documents analyzed is 471. The results show that research on TPACK is on the rise, increasing progressively in recent years. The main area of research is education and educational research, with articles, written in English, being the medium used by researchers to present their results. It can be concluded that, although there is an established research base, there is no single line of research. In this case, the main lines of research are "framework-framework-TPACK" and "technology-pedagogy-beliefs". It can be determined that the studies on TPACK deal with the integration of technological resources and the analysis of their perception in student learning.

Keywords: teaching–learning strategies; teacher professional development; 21st century abilities; lifelong learning; scientific mapping; bibliometric analysis; SciMAT; TPACK

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1. Introduction

Technological advances in the 21st century have flooded all facets of society, from commerce to education, from literature (e-books) to social relations (social networks such as Facebook, Twitter or Instagram). In the case of education, all over the world, information and communication technologies (ICTs) underpin the discourse of countless education reform movements [1,2]. Educational policymakers, stakeholders, researchers and educators argue that the shift from schools to the digital age is crucial for students' participation in contemporary society [3]. In this sense, as far as pre-service teachers are concerned, research has shown that attitudes towards the use of ICTs in education play a crucial role in the intention to use them [4]. The same applies to the preparation of schools, i.e., support, resources, perception of the importance of ICT integration and exchange of ideas among teachers. These are all vital aspects of ICT integration [5].

For this reason, the training of future teachers is a transcendental issue because of their involvement in effectively integrating technology into their future classrooms [6–8]. In many cases, this training is carried out through specific technological resource programs or training through online platforms [9]. However, recent research suggests the need for training strategies to have a more integrative and holistic approach [10]. From this perspective, the most current approaches to the development of teacher competence in technology integration have made technological knowledge alone less important. In this case, they have focused on the essential connections between technology, pedagogy and content knowledge (TPACK) [11,12].

TPACK is a framework for the integration of technology and teacher knowledge that combines technology, pedagogy and content [11]. It is based on Schulman's concept of pedagogical content knowledge (PCK) [13] where content and pedagogy are combined to understand how a given content requires specific pedagogical strategies for its teaching. TPACK [14,15] has also been described as a framework used to explain and describe teachers' knowledge and skills in relation to technology integration. The authors of Ref. [16] define it as "Knowledge of how to combine different areas, how to use appropriate pedagogical approaches for certain content with appropriate ICT".

The literature related to TPACK represents this integration framework with a Venn diagram in which the three primary forms of teacher knowledge are related: "content knowledge (CK)", "pedagogical knowledge (PK)" and "technological knowledge (TK)". The intersection of these three types of knowledge promotes four other components comprising content knowledge of technology (TCK), pedagogical content knowledge (PCK), pedagogical knowledge of technology (TPK) and TPACK. The latter would appear in the center of the diagram at the intersection of the three teacher's primary knowledge circles (Figure 1). In relation to the different elements that make up this framework, some researchers argue that the domains of basic knowledge in the TPACK framework are predictors of teachers' TPACK. PK has the greatest impact on teachers' TPACK prior to performance [17]. Other researchers suggest that, although TK, PK and CK are correlated with TPACK, TK is not a significant predictor of TPACK [18].

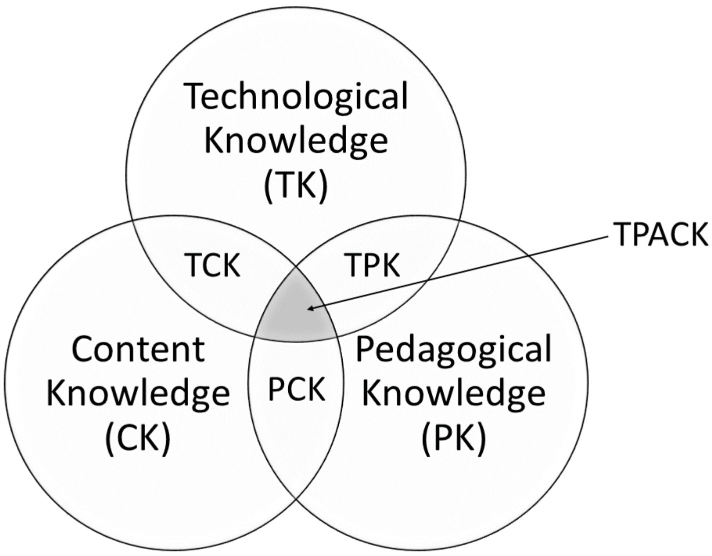


Figure 1. Technology, pedagogy and content knowledge (TPACK) framework.

Studies conducted over the past decade on the integration of technology into education through the TPACK framework support the validity of this model for teacher education [3,9,19–22]. The results of these studies show that the greatest progress is made in knowledge of educational content. Furthermore, improvements are greater in areas related to pedagogical knowledge than in areas related to technology or content knowledge. However, in areas without pedagogical knowledge, the changes are more moderate. Similarly, it is clear from this research that teachers in training need continuous feedback and assessment of their skills. This is necessary to help them further develop their knowledge, skills and attitudes related to the use of ICT in the classroom [23,24]. Thus, there is a need to provide them with opportunities to design lessons with ICTs, both in their teacher training courses and in their field experiences [25]. This would help them to develop their skills in the effective use of technology in their classrooms.

The TPACK model is used in a variety of important teaching and learning situations, such as foreign languages [14], professional development of teachers for the inclusion of specific software in social science classes [26], inclusion in special education schools for students with visual impairment [27], development of students' emotional intelligence [28] or training through virtual learning environments [29].

As we have seen, the importance of the TPACK model for training and learning using technology is a fact. This study aims to highlight the relevance of this model through the study of co-words in the articles indexed in the Web of Science database and to provide a concrete framework for research carried out using this training model. To this end, the present manuscript begins with an introduction that serves as a theoretical framework where the validity of the TPACK model is defined and explained. In a second section, the bibliometric analysis system to be followed and the objectives of the study are justified. Next, the materials and the method followed in the research are presented. The following section is devoted to the results, focusing on three aspects in particular: scientific performance and production, structural and thematic development and the authors with the highest relevance index. In the final phase of the study, the discussion, conclusions and implications are developed.

2. Justification and Objectives

This research addresses the analysis of the term TPACK in the educational field from a bibliometric approach. For this purpose, the documents indexed in the Web of Science (WoS) database were used. This database has been chosen because it is considered one of the largest databases that relates to the field of social sciences, with education being encompassed in this field of knowledge. Furthermore, Journal Citation Reports draws on this database. So, WoS studies of impact and scientific relevance are reported [30].

The novelty that this study has with respect to previous studies [31] focuses on an innovative technique of documentary analysis. In particular, in this work, an analysis of the performance and a scientific mapping of the publications related to the selected construct have been used. This study has followed the analytical structure of different impact publications with the purpose of carrying out effective research under a validated model [30,32].

Specifically, this study focuses on analyzing the significance and evolution of the TPACK concept in the publications contained in WoS. To the best of our knowledge, no study has been reported that analyzes this concept under the bibliometric technique of scientific mapping. Therefore, this research is developed from an exploratory perspective with the intention of showing the scientific community the progress achieved by TPACK in WoS documents and its future lines or trends. This will reduce the gap found in the literature on the state of the art and build the basis for future research. Therefore, the objectives formulated in this study are the following:

- To know the performance of scientific production on TPACK in WoS.
- To determine the scientific evolution in WoS of the term TPACK.
- To discover the most relevant topics about TPACK in the scientific literature indexed in WoS.
- To find the most representative authors in WoS who study the TPACK model.

3. Materials and Methods

3.1. Research Design

To develop the study and achieve the proposed objectives, research based on a bibliometric methodology has been designed [33,34]. This methodology assumes a relevant role in the quantification and integral evaluation of scientific documents [35,36]. This research design allows for efficiently carrying out the actions of searching, registration, analysis and prediction of the scientific literature [37,38].

The research method chosen was based on a co-word analysis [39], as well as on the h, g, hg and q2 indices [40,41]. The analysis of co-words allows us to analyze the keywords reported from the different scientific documents, with the purpose of looking for connections between the topics studied on the state of the question, as well as predicting the issues that could potentially be considered in the near future [42]. This analytical approach has allowed the creation of maps with nodes to represent yield, the location of terminological subdomains and thematic development [43] on TPACK in the documents registered in WoS.

3.2. Procedure

The research has followed a strict and structured procedure in different phases, in order to reduce the appearance of bias in the study, as required by this type of analysis [44,45].

- Firstly, the database to be analyzed (WoS) was selected.
- Secondly, the keywords that would allow the production of a documentary report were defined ("TPACK", "TPCK" and "technology pedagogy and content knowledge").
- Thirdly, the following search equation was developed: ("TPACK" OR "TPCK" OR "technological pedagogy and content knowledge" OR "technology pedagogy content knowledge") TITLE. This equation was used to search the titles of WoS publications.

This search equation was applied in the main WoS collection, since the field of education is implicit in the concept analyzed. The search and reporting process took place in November 2020. In the final document report, it was decided to choose all types of documents and languages to encompass all the WoS literature on the state of the issue.

These actions resulted in a total of 556 publications. The purification of this documentary volume was carried out by establishing different criteria. The following were established as exclusion criteria: documents published in the year 2020 (for not having finished the year); documents repeated or badly indexed in WoS. The inclusion criterion is referring to the above-mentioned subject matter. The application of these criteria produced a final unit of analysis of 471 scientific documents. The actions followed are shown in the following flow chart according to the PRISMA declaration and the protocol derived from it (Figure 2). This figure shows the different actions included in the standardized protocol of PRISMA, where the initial report of documents on the analyzed construct is established and the reductions suffered by the initial volume after the application of the matrix criteria, until reaching the final unit of analysis established in this study.

3.3. Data Analysis

Data analysis was performed using the programs Analyze Results, Creation Citation Report and SciMAT [46]. The first two were used to collect and study the year, authorship, country, type of document, institution, language, medium and most cited documents. The inclusion criteria to show the data were: year of publication (all except 2020); language ($x \geq 2$); publication area ($x \geq 10$); type of documents ($x \geq 10$); organizations ($x \geq 15$); authors ($x \geq 9$); sources of origin ($x \geq 14$); countries ($x \geq 40$); the eight most cited documents ($x \geq 271$). These criteria are associated with a numbering that refers to the number that must be met in each case (criterion) for the publications to be included in the analytical tables presented in this work. Otherwise, the generated tables would be very long. It must be specified that all the literature has been analyzed, but only the documents that meet the criteria are established in the tables of this manuscript.

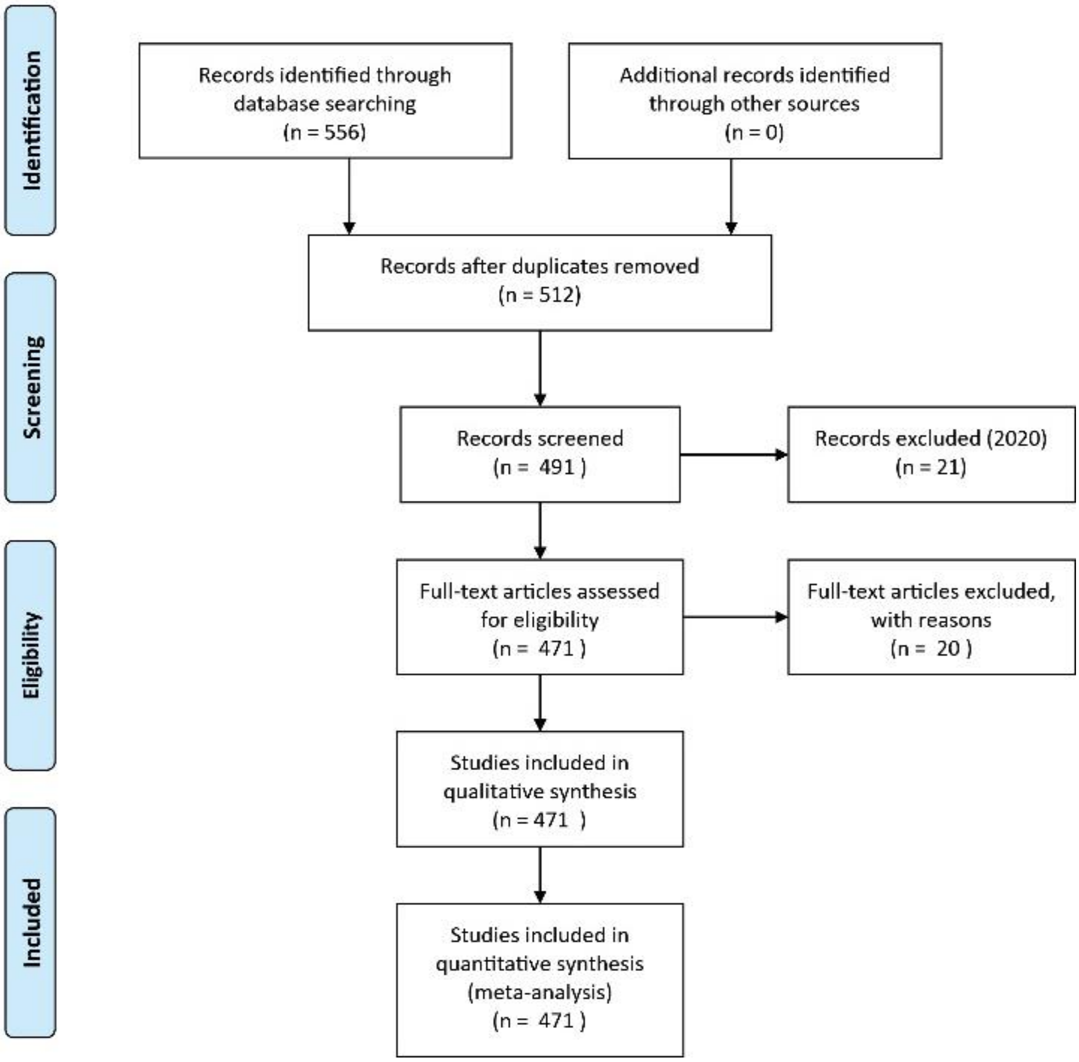


Figure 2. Flowchart according to the PRISMA declaration.

SciMAT was used to materialize the structural and dynamic development of publications from a longitudinal perspective. That is, it analyzes the evolution of a keyword transformed into a theme in established periods over time. Note that this follows the considerations of previous studies [47,48].

Co-word analysis was performed with SciMAT using the following processes [49,50]:

- Recognition: The keywords of the reported WoS documents were analyzed (n = 1061). Co-occurrence node maps were made. A standardized co-word network was designed and the most significant keywords (n = 1000) were extracted. The most outstanding topics and terms were determined with a clustering algorithm.
- Reproduction: Different thematic networks were generated (Figure 3a,b), where the connections between a main focus and its derived conceptual associations are visually reflected, as well as strategic diagrams to place each of the constructs according to their projection. These were divided (Figure 3a) into four quadrants (Q): top right (Q1) = driving and relevant issues; top left (Q2) = deep-rooted and isolated problems; bottom left (Q3) = emerging or disappearing problems; bottom right (Q4) = cross-cutting and underdeveloped issues. The principles of density and centrality were respected. Density measures the internal strength of the network. Centrality measures the level of connection of a network with others [51].
- Determination: The documentary report was articulated in different periods with the purpose of analyzing the progression of the nodes in different periods of time. Specifi-

cally, three periods were established (P_1 = 2006–2014; P_2 = 2015–2017; P_3 = 2018–2019). The criterion taken for this temporal configuration was based on the achievement of similarity in the number of documents between the different periods. However, for the author-focused analysis, we simply determined an overall period that encompasses the entire temporality of publications (P_X = 2006–2019). To find the strength of the association between periods, the number of keywords or subjects in common between them was taken as a reference.

- Performance: Several production indicators associated with the inclusion criteria [52] (Table 1) were established and the themes developed over the established time periods were analyzed (Figure 3c).

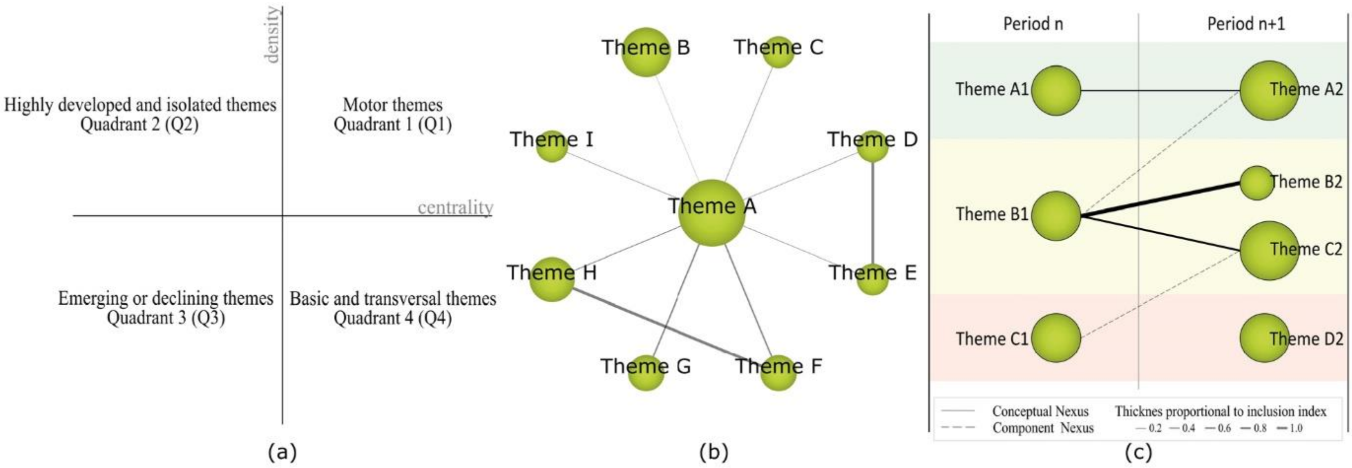


Figure 3. (**a**) Strategic diagram; (**b**) Thematic network; (**c**) Thematic evolution [40].

Table 1. Production indicators and inclusion criteria.

Configuration	Values
Analysis unit	Keywords authors, keywords Web of Science (WoS)
Frequency threshold	Keywords: P_1 = (2), P_2 = (2), P_3 = (2) Authors: P_X = (2)
Network type	Co-occurrence
Co-occurrence union value threshold	Keywords: P_1 = (2), P_2 = (2), P_3 = (1) Authors: P_X = (2)
Normalization measure	Equivalence index: eij = cij2/Root (ci − cj)
Clustering algorithm	Maximum size: 9; Minimum size: 3
Evolutionary measure	Jaccard index
Overlapping measure	Inclusion rate

4. Results

4.1. Scientific Performance and Production

There are a total of 471 documents on studies related to the term TPACK in the WoS database. The production of these documents began to be registered in this database in 2006. Specifically, two manuscripts, which refer to the pedagogical innovation involved in the use of ICT in education [53], and the qualities of teachers who use ICT in training processes [54]. This shows that it is a relatively young field of research. From 2006 to 2019, production has been increasing, with two notable production peaks; one stands out in 2013 and another in 2017. As can be seen in Figure 4, the term TPACK may be prevented from gaining more interest in the scientific community. It is true that the volume of production does not exceed 90 manuscripts in any of the years analyzed. Although the evolution is upward in terms of the number of publications, it is remarkable that the ascending evolution is not regular.

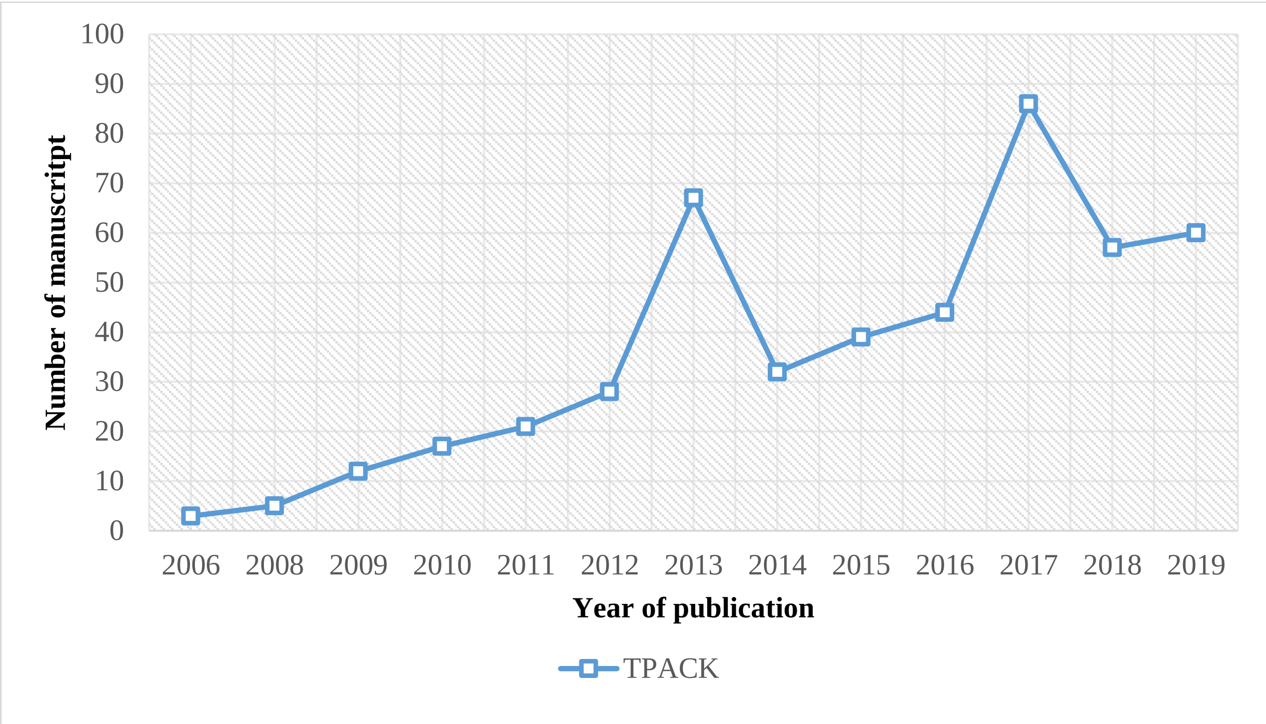


Figure 4. Evolution of scientific production.

Taking into account what is established in Table 2, it can be indicated that English is the language chosen by the scientific community to present studies related to TPACK. It is followed by Spanish. With respect to the type of document, articles are the most used by the researchers. This is followed by proceedings papers. In terms of organization, Nanyang Technological University stands out above the rest, although it is followed, at a short distance, by the National Institute of Education (NIE) Singapore.

Table 2. Language, type of documents and organization in the field of TPACK research.

Language	Publications	Organizations	Publications
English	470	Nanyang Technological University	39
Spanish	18	National Institute of Education (NIE) Singapore	29
Turkish	8	National Taiwan University of Science Technology	20

Type of documents	Publications
Article	337
Proceedings paper	97
Book chapter	25

In relation to the area of publication, research related to TPACK is mainly found in education and educational research. The rest of the areas are rarer. With respect to the authors, it is Chai, C.S. that accumulates the most production in this type of study. He is followed, at a considerable distance, by Koh, J.H.L. In relation to the source of production, there are mainly two, the *Australasian Journal of Educational Technology* and *Computers & Education*. Among the countries with more production, the United States is the nation that researches most in this field of study. It is followed, at a considerable distance, by Turkey (Table 3).

Table 3. Areas of knowledge, authors, sources and countries in the field of TPACK research.

Areas of Knowledge	Publications	Author	Publications	Countries	Publications
Education and Educational Research	421	Chai, C.S.	37	United States	124
Education Scientific Disciplines	52	Koh, J.H.L.	27	Turkey	80
Computer Science Interdisciplinary Applications	51	Tsai, C.C.	18	Taiwan	51
Computer Science Theory Methods	15	Tondeur, J.	9	China	49
Linguistics	11				

Sources	Publications
Australasian Journal of Educational Technology	25
Computers & Education	23
Journal of Research on Technology in Education	22
Journal of Educational Computing Research	20

Among the most cited articles on studies related to TPACK, the study by Mishra and Koehler (2006) stands out mainly due to its large number of citations, with a total of 2238 citations. This study refers to the establishment of a conceptual framework related to educational technology and the formulation of [11] on "pedagogical content knowledge". The next most cited article is by [55], with a total of 380 citations. This research focuses on determining and specifying the different pedagogical models related to the development of the ICT-TPCK model (Table 4).

Table 4. TPACK: most cited articles.

Reference	Citations
Mishra, P.; Koehler, M. (2006). Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge [11]	2238
Angeli, C.; Valanides, N. (2009). Epistemological and methodological issues for the conceptualization, development, and assessment of ICT-TPCK: Advances in technological pedagogical content knowledge (TPCK) [55]	380
Schmidf, D.A.; Baran, E.; Thompson, A.D.; Mishra, P.; Koehler, M.J.; Shin, T.S. (2009). Technological Pedagogical Content Knowledge (TPACK): The Development and Validation of an Assessment Instrument for Preservice Teachers [56]	378
Harris, J.; Mishra, P.; Koehler, M. (2009). Teachers' Technological Pedagogical Content Knowledge and Learning Activity Types: Curriculum-based Technology Integration Reframed [57]	272
Voogt, J.; Fisser, P.; Roblin, N-P.; Tondeur, J.; Van Braak, J. (2013). Technological pedagogical content knowledge-a review of the literature [58]	205
Graham, C.R. (2011). Theoretical considerations for understanding technological pedagogical content knowledge (TPACK) [59]	190
Tsai, C.C.; Lee, M.H. (2010). Exploring teachers' perceived self efficacy and technological pedagogical content knowledge with respect to educational use of the World Wide Web [60]	187
Archambault, L.M.; Bernett, J.H. (2010). Revisiting technological pedagogical content knowledge: Exploring the TPACK framework [61]	181

4.2. Structural and Thematic Development

The evolution of the keywords between the different established time periods shows the level of coincidence of keywords. The information provided includes the number of keywords that are no longer present in the next period (represented by an upward and oblique arrow), the keywords that are included as new, compared to a previous period, in the new period (represented by a downward and oblique arrow), the keywords that exist in a given period (represented within a circle) and the matching percentage of keywords between periods (represented by a horizontal arrow pointing to the right). In this case, Figure 5 shows that the field of study on TPACK has a solid research base. In other words, the scientific community orients its research on related aspects. This is contrasted by the fact that the level of coincidence of keywords between periods is over 35%. In addition, there is a higher level of awareness between the first and second period than between the second and third period. This may indicate a change in the lines of research by the scientific community.

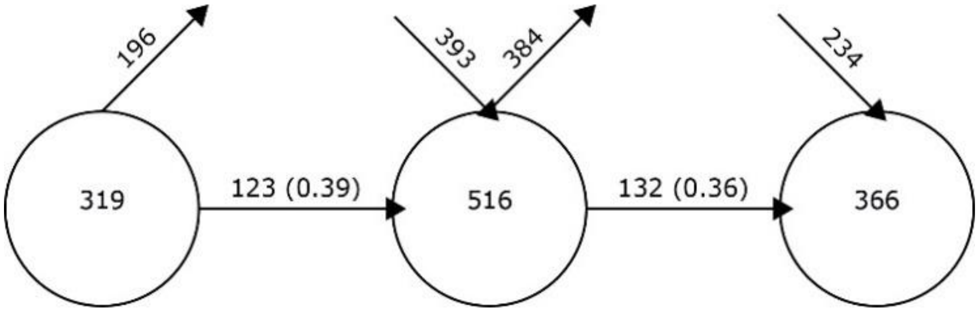


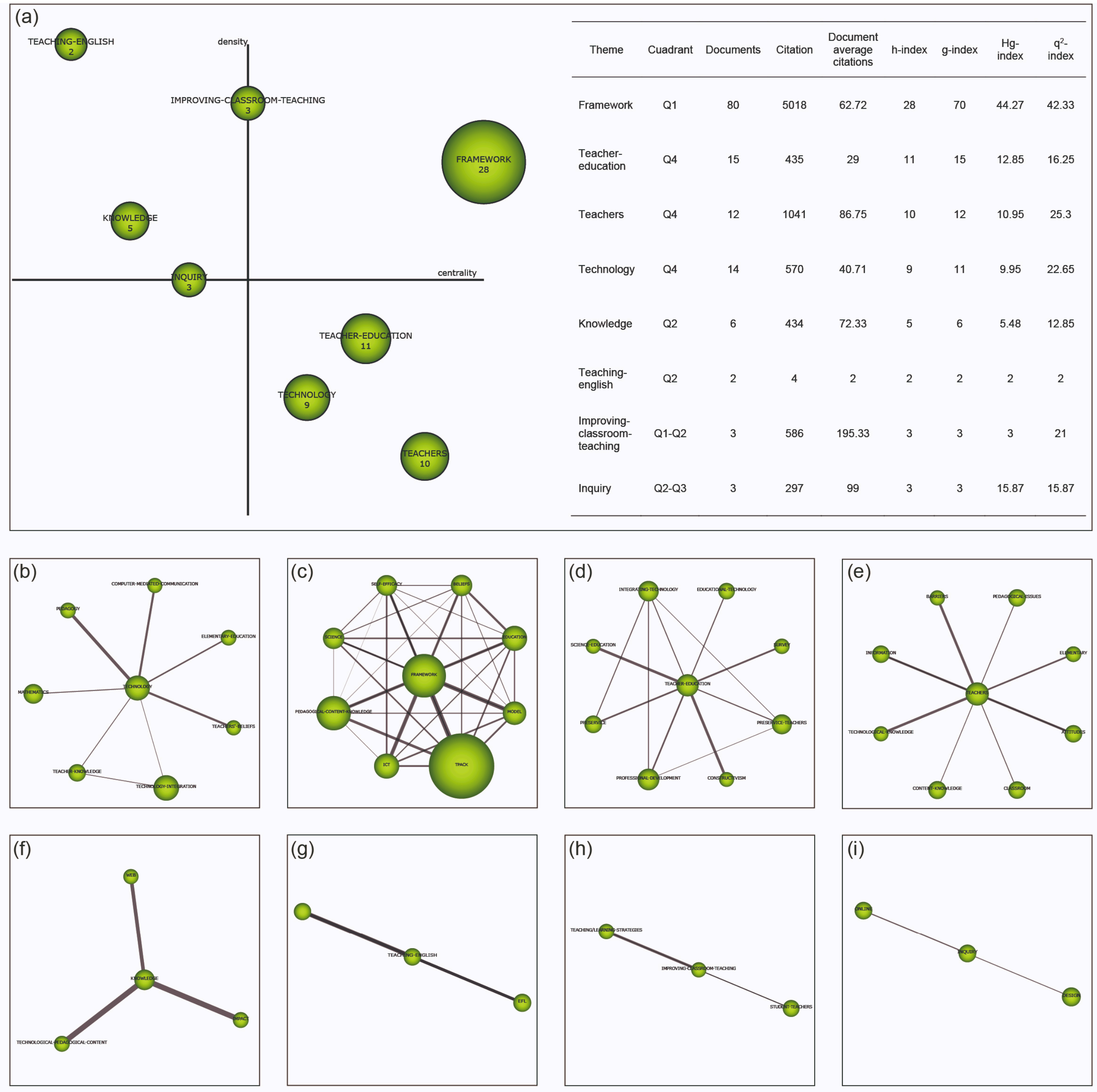
Figure 5. Continuity of keywords between contiguous intervals.

The academic performance of the established periods presents the most relevant themes and with the most values in the bibliometric indices, among which are the h index, the g index, the hg index and the q2 index. On the other hand, the interval diagram tries to show the level of importance of each of the analyzed subjects in the subject performance. To this end, it takes into account a process of grouping, by means of the Callon index [62]. This indicator analyzes the degree of interaction of a network with respect to other networks, from two perspectives: centrality, which measures the strength of external links with other topics, being the measure of the importance of a topic in the development of a certain field of research; and density, which analyzes the internal strength of the network, identifying the internal links between all the keywords that are grouped around a specific topic, thus offering the degree of development of the field of study analyzed.

As established in Figure 6, in the first period (2006–2014), the theme with the highest academic performance, that is, the one with the most bibliometric values, is “framework”. It is followed, at a very considerable distance, by “teacher-education” and “teachers”. In addition, the “framework” theme is considered in this period as the driving theme, since it is located in the Q1 quadrant. This theme is related to “self-efficacy”, “beliefs”, “education”, “model”, “tpack”, “ICT”, “pedagogical-content-knowledge” and “science”. It can be indicated, therefore, that in this period, studies on TPACK focused on the model itself, on the technological resources used for its application and on the perception of its validity by those involved in the teaching and learning processes.

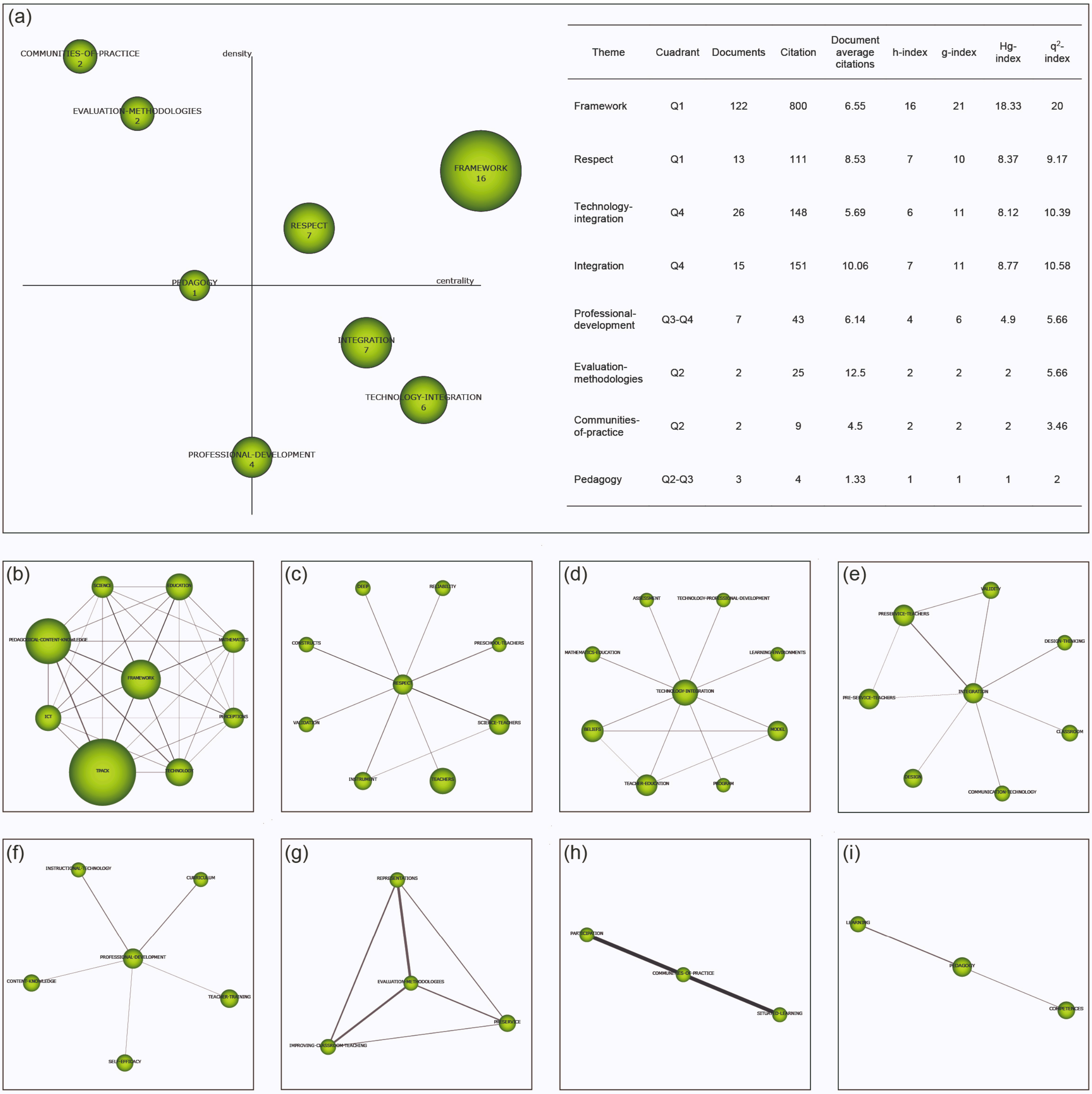
In the second period (2015–2017), the framework theme is again the one with the highest bibliometric levels. It is followed, far behind, by the themes of “technology integration”, “integration” and “respect”. In this period, two themes are considered to be the driving forces, the case of “framework”, which is repeated, and “respect”. In this case, the “framework” theme is related to “science”, “education”, “mathematics”, “perception”, “technology”, “tpack”, “ICT” and “pedagogical-content-knowledge”. The theme “respect”, on the other hand, relates to “DEEP”, “reliability”, “preschool-teachers”, “science-teachers”, “teachers”, “instrument”, “validation” and “construct”. It is therefore shown that this second period follows the lines of investigation set out in the first period, but with some minor nuances. In this period of time, research is extended to the field of mathematics, in addition to establishing instruments for the analysis of this method of study (Figure 7).

In the third and last period (2018–2019), there is a change of trend with respect to the two previous periods. The theme with the highest bibliometric value is “TPACK”, followed by “education”. In this time interval, the themes considered to be driving forces are “validity” which is related to “confirmatory-factor-analysis”, “FIT”, “scale”, “self-efficacy”, “respect”, “instrument”, “efficacy” and “quality”; “education” which is related to “design-thinking”, “structural-equation-modelling”, “inquiry”, “attitudes”, “design”, “pre-service-teachers”, “framework” and “support”; “teacher-beliefs” which relates to “integration”, “construction”, “online-teaching”, “classroom”, “conceptualization”, “program”, “professional-development” and “achievement”; and “TPACK” which relates to “technology-integration”, “pedagogical-content-knowledge”, “teacher-education”, “perceptions”, “pre-service-teachers”, “teachers”, “technology” and “ICT”. In other words, in this last period, the most relevant lines of research are focused on the validation of the evaluation instruments of the TPACK model and on the perception of the teachers themselves in the application of this educational model. In addition, in this last period, the topics "knowledge" and "higher education" should be taken into account, given that their location in the diagram places them as unknown topics. This means that in the next few years, they may disappear from this field of research, or they may become the next driving forces. Therefore, new lines of research can be found (Figure 8).



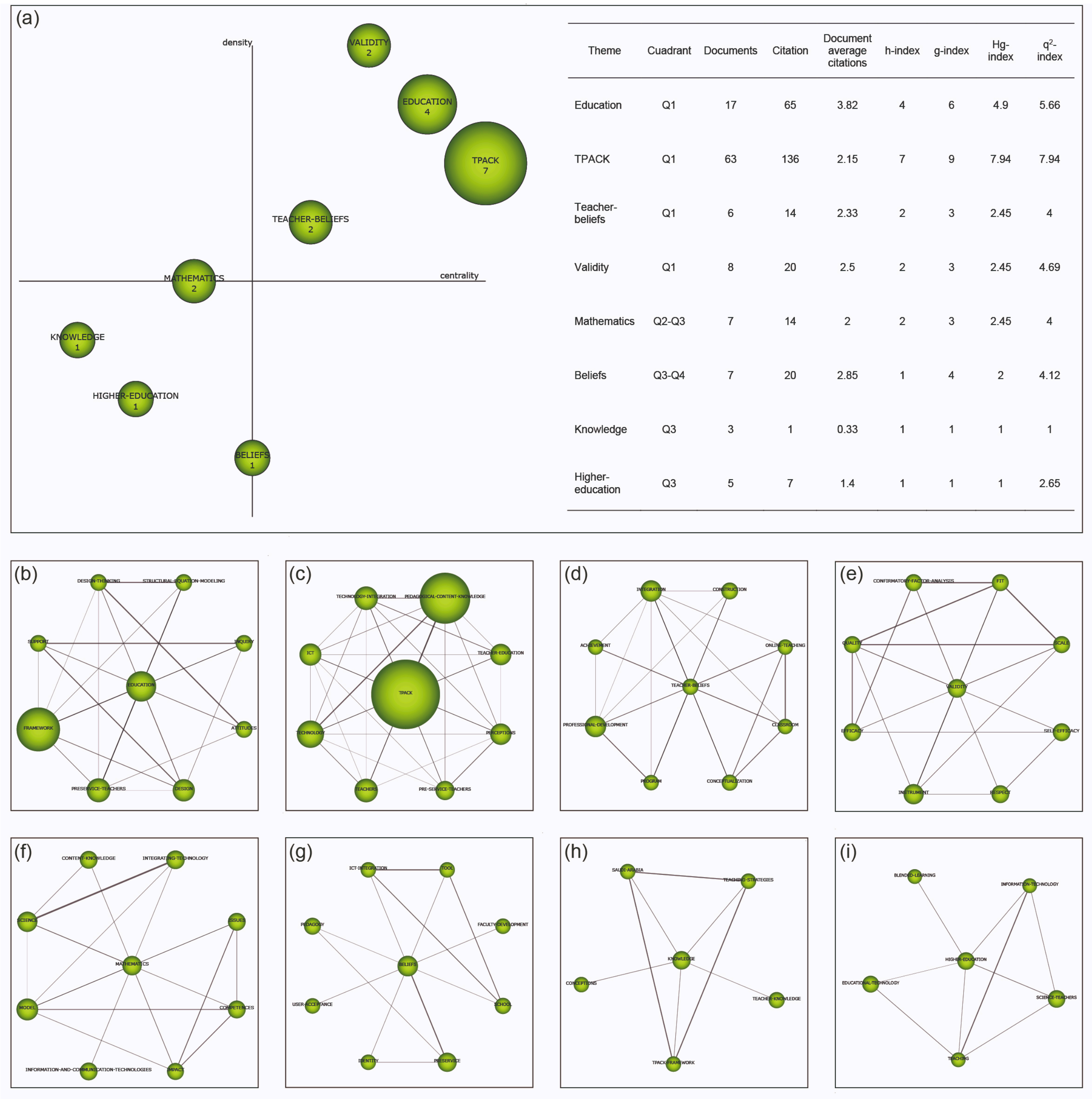
Theme	Cuadrant	Documents	Citation	Document average citations	h-index	g-index	Hg-index	q^2-index
Framework	Q1	80	5018	62.72	28	70	44.27	42.33
Teacher-education	Q4	15	435	29	11	15	12.85	16.25
Teachers	Q4	12	1041	86.75	10	12	10.95	25.3
Technology	Q4	14	570	40.71	9	11	9.95	22.65
Knowledge	Q2	6	434	72.33	5	6	5.48	12.85
Teaching-english	Q2	2	4	2	2	2	2	2
Improving-classroom-teaching	Q1-Q2	3	586	195.33	3	3	3	21
Inquiry	Q2-Q3	3	297	99	3	3	15.87	15.87

Figure 6. (**a**) Strategic diagram (index h) and performance from 2006 to 2014. (**b**) "technology" theme. (**c**) "framework" theme. (**d**) "teacher-education" theme. (**e**) "teachers" theme. (**f**) "knowledge" theme. (**g**) "teaching-English" theme. (**h**) "improving-classroom-teaching" theme. (**i**) "inquiry" theme.



Theme	Cuadrant	Documents	Citation	Document average citations	h-index	g-index	Hg-index	q^2-index
Framework	Q1	122	800	6.55	16	21	18.33	20
Respect	Q1	13	111	8.53	7	10	8.37	9.17
Technology-integration	Q4	26	148	5.69	6	11	8.12	10.39
Integration	Q4	15	151	10.06	7	11	8.77	10.58
Professional-development	Q3-Q4	7	43	6.14	4	6	4.9	5.66
Evaluation-methodologies	Q2	2	25	12.5	2	2	2	5.66
Communities-of-practice	Q2	2	9	4.5	2	2	2	3.46
Pedagogy	Q2-Q3	3	4	1.33	1	1	1	2

Figure 7. (**a**) Strategic diagram (index h) and performance from 2015 to 2017. (**b**) "framework" theme. (**c**) "respect" theme. (**d**) "technology-integration" theme. (**e**) "integration" theme. (**f**) "professional-development" theme. (**g**) "evaluation-methodologies" theme. (**h**) "communities-of-practice" theme. (**i**) "pedagogy" theme.



Theme	Cuadrant	Documents	Citation	Document average citations	h-index	g-index	Hg-index	q²-index
Education	Q1	17	65	3.82	4	6	4.9	5.66
TPACK	Q1	63	136	2.15	7	9	7.94	7.94
Teacher-beliefs	Q1	6	14	2.33	2	3	2.45	4
Validity	Q1	8	20	2.5	2	3	2.45	4.69
Mathematics	Q2-Q3	7	14	2	2	3	2.45	4
Beliefs	Q3-Q4	7	20	2.85	1	4	2	4.12
Knowledge	Q3	3	1	0.33	1	1	1	1
Higher-education	Q3	5	7	1.4	1	1	1	2.65

Figure 8. (**a**) Strategic diagram (index h) and performance from 2018 to 2019. (**b**) "education" theme. (**c**) "TPACK" theme. (**d**) "teacher-beliefs" theme. (**e**) "validity" theme. (**f**) "mathematics" theme. (**g**) "beliefs" theme. (**h**) "knowledge" theme. (**i**) "higher-education" theme.

Figures 6–8 are reflected in Table 5, which shows the position of the different themes, as well as the values of density and centrality. It can also be seen that only two themes are repeated in other periods. This is the case of the "framework" and "knowledge" themes.

Table 5. Principal research themes related to TPACK from 2006 to 2019.

Theme	P1 (2006–2014)	P2 (2015–2017)	P3 (2018–2019)
Framework	Q1 (98.51/30.44)	Q1 (112.1/36.5)	
Teacher-education	Q4 (37.86/9.25)		
Teachers	Q4 (50.98/7.19)		
Technology	Q4 (30.95/7.23)		
Knowledge	Q2 (5.78/8.18)		Q3 (28.43/18.98)
Teaching-English	Q2 (3.91/77.78)		
Improving-classroom-teachings	Q1–Q2 (18.54/37.96)		
Inquiry	Q2–Q3 (11.56/13.89)		
Respect		Q1 (30.8/10.9)	
Technology-integration		Q4 (45.95/7.62)	
Integration		Q4 (38.03/8.1)	
Professional-development		Q3-Q4 (17.9/6.6)	
Evaluation-methodologies		Q2 (6.1/52.98)	
Communities-of-practice		Q2 (1.25/100)	
Pedagogy		Q2–Q3 (6.99/10.37)	
TPACK			Q1 (119.93/27.96)
Education			Q1 (103.6/29.7)
Validity			Q1 (69.67/30.86)
Teacher-beliefs			Q1 (69.04/27.55)
Mathematics			Q2–Q3 (61.75/20.53)
Higher-education			Q3 (42.99/15.19)
Beliefs			Q3–Q4 (63.5/14.3)

The thematic evolution indicates the strength of the relationship between the different themes of the established time periods. The Jaccard index is taken into account for this purpose. The evolution between themes occurs when a certain period shares keywords or themes with respect to the contiguous time interval. The greater the number of keywords or themes in common, the greater the probability the relationship would work. The types of connections that exist are: continuous line, whose connection is thematic; and discontinuous line, whose connection is of keywords. The thickness of the lines offers the strength of the interrelation between the themes.

As shown in Figure 9, it can be seen that there is a conceptual gap. That is to say, there is not one theme that is repeated in all three periods. This does not mean that there is no line of research over time. In this case, the "framework-framework-tpack" line of research can be highlighted, which is the one that presents the most strength and strongest relationship. There is another line of research that stands out, although its strength over time is not as high as the previous one. This is the case of "technology-pedagogy-beliefs" or "technology-framework-mathematics", "technology-technology_integration_tpack". It should be noted that there are an even number of connections, both conceptual and non-conceptual. This shows that there is a large number of investigations that are based on the same theme, although there are others that are not.

4.3. Authors with the Highest Relevance Index

Focusing the field of study on the authors themselves, and taking into account what is established in Figure 10, it can be said that the most relevant authors in this field of study are Guzey, S.S., Finger, G. and Tondeus, J. Furthermore, due to the position in the diagram, it can be seen that the authors Tokmak, H.S. and Jang, S.J. may be the most relevant authors in the coming years in this field of study. There are other authors located in Q2 and Q4 of the diagram, who are considered to be highly developed and isolated authors or basic and transversal authors. In this case, although they continue to be of interest to the scientific community and are important in this field of study, they are not considered the most influential and relevant in this field of study.

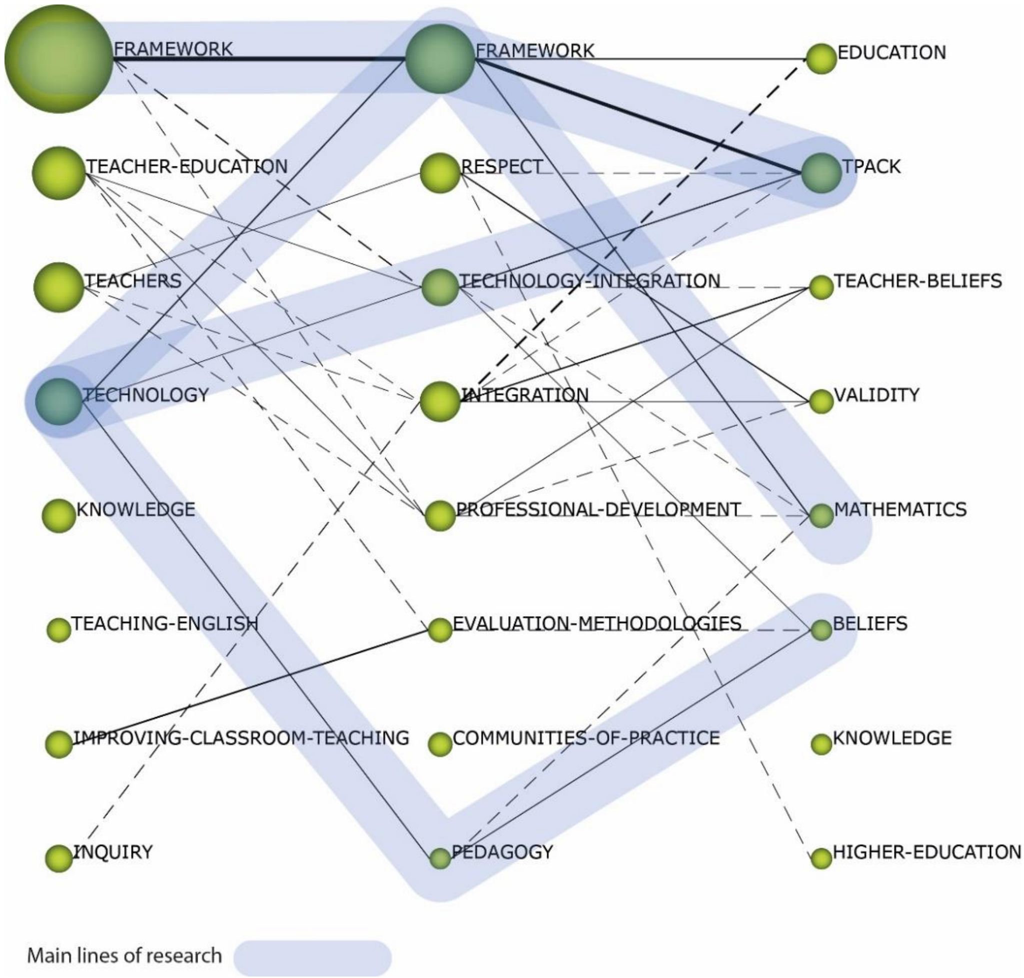


Figure 9. Thematic evolution by h-index.

5. Discussion

Undoubtedly, the so-called technological advances have an impact on all sectors of society, from a change in social relations to a new form of learning. In particular, ICTs have favored the development of teaching–learning processes considerably [1,2]. They are a technological tool that increases student motivation and allows for the transmission of content favoring social, active and participatory learning [5]. This digital awakening allows students to be part of a new society that, in the educational field, requires highly qualified professionals [3,4,6–8].

The participation of teachers in technological resource training programs allows these tools to be exploited in the classroom in a didactic way [9]. However, as stated in the theoretical framework, it is essential that training strategies are based on holistic, global and integrative approaches, i.e., that the underlying methodology is in line with the objectives of the activities [10]. Indeed, digital competence must go beyond this. We have seen how the integration of technology into education through the TPACK framework [11–13] promotes teacher training in the use of digital competence and offers the necessary pedagogical strategies [3,9,14–16,19–22].

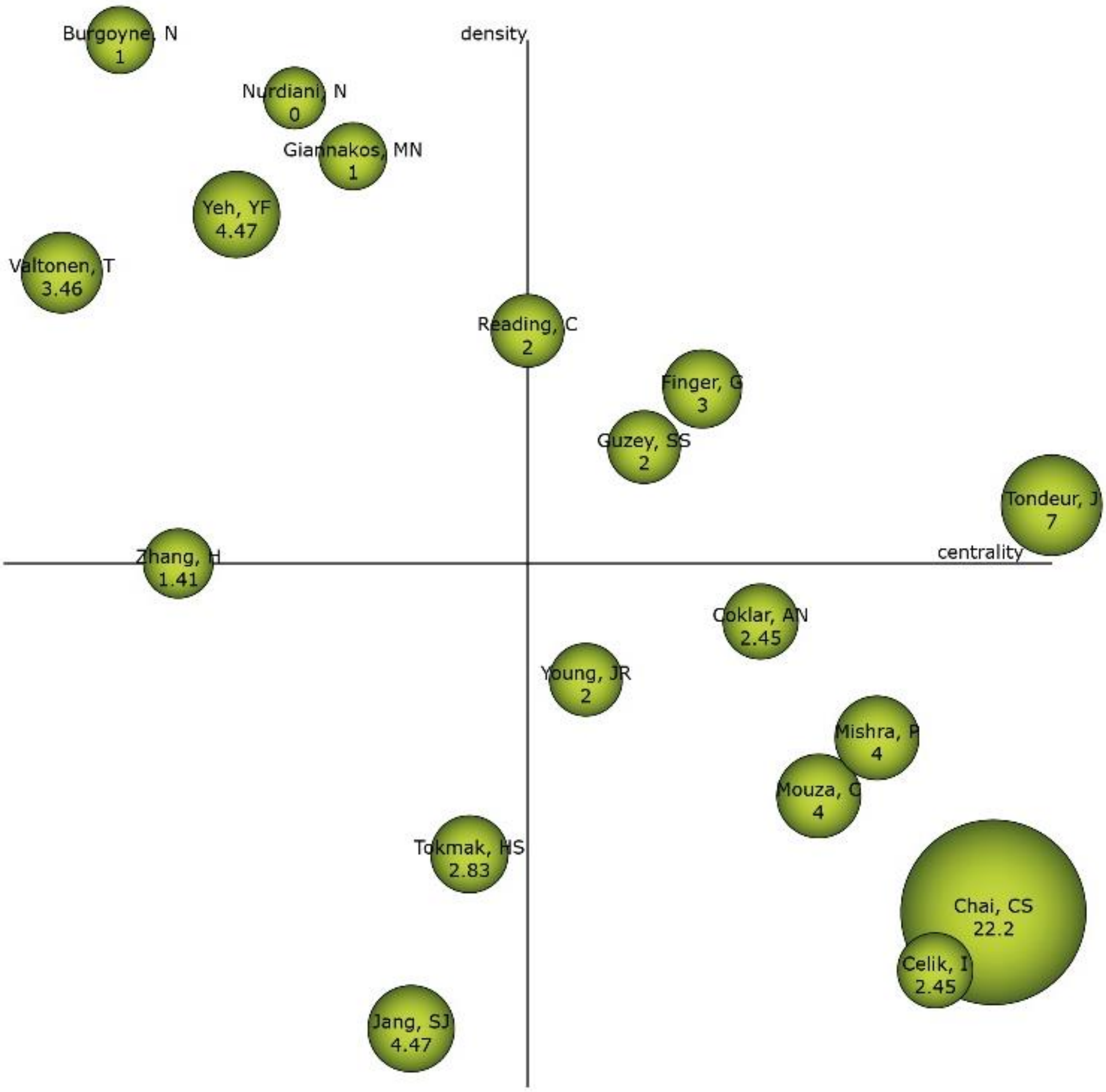


Figure 10. Strategic author diagram of the entire production.

The advances allow us to affirm that greater success is achieved when this framework is applied to areas related to pedagogical knowledge. This shows that other areas that are not related have less evolution and, therefore, less change. However, teachers in training must be offered constant feedback and continuous assessment in order to achieve greater inclusion of these technologies in the classroom [23,24]. Teaching programs and teaching guides, that is, curriculum planning instruments, should be configured around these ideas, with the related methodology [25].

Note that the performance profile of scientific production is 471 documents, which gives it an upward trend, although, as shown, with production peaks in 2013 and 2017. It should be noted that the beginning of scientific production is 2006, which makes it a rather young subject, developed in English, with publications in an article format. The organization of Nanyang Technological University, the area of publication of education and educational research and the author with the highest production, Chai, C.S., stand out. However, other authors considered as relevant are Guzey, S.S., Finger, G. and Tondeus, J. The source of production is the *Australasian Journal of Educational Technology*, and the most prolific country is the United States. Significantly, the most cited document is that of [11], with 2238 citations.

It should also be noted that the evolution of keywords clearly indicates the existence of a consolidated research base. In fact, this bibliometric study allows us to affirm that the period between 2006 and 2014, that is, the first period, includes the subject matter with the highest academic performance, with "framework" as the subject matter with the most bibliometric values. This is followed by "teacher-education" and "teachers". This shows that in this period, the studies on the TPACK method were focused on the integration of technological resources and on the analysis of their perception in student learning.

Thus, the second period (2015–2017) shows that the framework theme continues to be by far the one with the highest academic performance. The fundamental difference is that this period also seems to be characterized by the themes "technology-integration", "integration" and "respect". Furthermore, it represents a continuation of the line of research already begun in the previous period with the systematic evolution of other research in the area of mathematics. Last, but not least, the third period (2018–2019) shows a radical change of trend, and now the subject that shows the highest index of representation is "TPACK", together with "education". This indicates that the lines of research of this period change substantially to focus on the validation of the assessment instruments of the TPACK model.

However, this bibliometric study allows us to affirm that there is not a theme that is repeated in a systematic way in the three periods, that is to say, the line of investigation "framework-framework-tpack" is consolidated as the line that acquires more strength, and the line "technology-pedagogy-beliefs" also grows. This clearly shows that the research carried out in these periods is focused on the same predominant theme.

6. Conclusions

In summary, this study of the TPACK model from the bibliometric analysis allows the researcher to offer a set of trends in the topics that the scientific community generates as new and necessary. Thus, it shows an epistemological and terminological knowledge that, together with the scientific one, contributes to its diffusion as a teaching method. The prospective of this research allows us to affirm that the results can help many researchers to value the inclusion of this model in the teaching–learning processes. Although educational technologies with this model contribute to the dissemination of pedagogical knowledge, they also require constant teacher training processes to obtain the best results.

Primarily, in this study, we have shown that the TPACK model can address the challenge of sustainability, that it can improve the aims of future research and how it can provide new findings to overcome epistemological and terminological emerging needs. Once again, the value of this model is unquestionable because it can help different professionals in the development of training processes.

The limitations of this research include the debugging of the WoS data. We need to insist on the fact that this research only focuses on a single database and, for this reason, this constitutes one study limitation. Furthermore, there are repeated documents, and others that are not related to the subject of the study. On the other hand, it is worth mentioning that the time periods are not regularly maintained, i.e., the analyzed documents show great differences depending on the analysis interval. Finally, the parameters of this research have been set based on the researchers' own criteria, always with the aim of showing consistent results. For this reason, it is considered that the data analyzed can be extrapolated to other research, but this should be done with caution. Although further research can be enriched, it can also counteract the parameters and modify the connections in the subjects analyzed. As for future lines of research, it should be stated that it would be convenient and necessary to carry out a study on the TPACK method in other specific areas of knowledge, such as, for example, the social sciences. In particular, in these areas of knowledge, it would be highly beneficial to know data of this type.

7. Implications of the Study

This study is the first work that has analyzed the TPACK model from a deeper bibliometric perspective, through the scientific mapping of the concept. The results achieved in this research have given rise to various theoretical and practical implications. At a theoretical level, the present work contributes to the increase in the scientific literature on TPACK. In addition, the findings obtained have allowed determining the trends running through the field of study on the state of the art. This allows the scientific community to be guided on the main focuses of interest that researchers have been taking during their scientific production and where research is heading. Likewise, the results have made it possible to reveal the profile of the studies carried out on TPACK, alluding to the various bibliometric indicators analyzed. These can serve as a guide and support for future work by other scientists who need to consult information, with that on languages, institutions, media and areas of publication, authors and most cited documents among the most prominent. Additionally, within the theoretical spectrum, the literature reflects with special relevance the validation of questionnaires about the different applications of the TPACK model. In this sense, the publications show the pedagogical prospects this model acquires in the field of education. The main purpose is to orientate future research and serve as a theoretical and conceptual framework for the teaching community in its applicability to learning spaces.

On the other hand, this study leaves a series of practical implications of interest for various groups related to the educational field. This ranges from teachers, researchers and students, to entities and institutions in charge of training and the development of innovative educational tools. Among the findings more focused on teaching practice, the scientific literature shows the main pedagogical methods carried out in different contexts, as well as their results and benefits in the application of the TPACK model. Along the same lines, the studies carried out to date show the potential that educational technology has obtained in its application in learning spaces and how teachers have integrated it into their professional practice. In addition, the research carried out includes the beliefs and perceptions of both teachers and students regarding the TPACK model. This acquires a supreme value, since its acceptance by the different members of the educational community will allow its promotion and deployment. All this will lead to the development of training actions and the improvement of a teaching and learning process typical of a technological era. Finally, the results obtained can serve as a guide for the entities and institutions in charge of developing training plans and digital applications, with the purpose of knowing the educational reality of this model and developing proposals that contribute to its development and integration in the training processes.

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