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Technological, Pedagogical, Content Knowledge (TPACK) Research Trends: A Systematic Literature Review of Publications Between 2010 - 2020

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ABSTRACT
The objective of the article review was to investigate research trends related to the TPACK topic, which is particularly useful for developing teacher learning abilities in line with the period of the industrial revolution 4.0, which uses a lot of technology integration in learning. This study is a TPACK systematic literature review out of 184 journal articles indexed by Scopus, published between 2010 and 2020. Findings show the countries that are the most TPACK research areas are Turkey and the United States. TPACK's research-related articles are published mostly in technology-based education-oriented journals. There are still a few journals based on science education research that publish articles on TPACK. Topics about the components of knowledge in TPACK are the most researched, namely Knowledge, Technology, Content, and Pedagogical. The least studied is development and integration, which means that these two topics have not been of much interest to researchers in the last ten years. From several analyses in this literature review, we suggest various references and reference centers of TPACK in science education and formulate what topics need to be researched for further research.

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Introduction

The development of Information and Communication Technology (ICT) in the Industrial Revolution 4.0 (4IR) has spurred the very rapid growth of the world in the 21st-century era (Shafie et al., 2019). This era involves technology that changes the social, economic, and even educational scenarios (Shafie et al., 2019). The form of change is that learning for 21st-century students or what is known as millennials is very different from students of previous generations. Millennial students and students rely heavily on technology (Lemley et al., 2014; Elam et al., 2007) because their lives are encompassed by technology and innovation. They moreover learn a part with the technology and innovation around them. Thus, of course, requires teachers to rely exclusively no longer on the chalk and conversation strategy or explaining in front of the class with a blackboard in learning (Shafie et

al., 2019). Therefore, science teachers, today must be aware of the demands of 4IR so that teaching in the classroom must change according to 21st-century learning (Shafie et al., 2019; Zorlu and Zorlu, 2021). Teaching methods should lead to Education 4.0, a term that came after 4IR. Education 4.0 responds to the need for 4IR in which humans and technology are adjusted to empower unused conceivable outcomes to enable new possibilities (Anealka, 2018). The most recent advanced technologies such as robotics, the Internet of Things (IoT), and artificial intelligence will supplant a few human employments within the future. Therefore, it is essential for students today to have skills that cannot be replaced by technology. Thus, where 21st-century abilities take place in education today. For students to remain relevant in the workplace, science instructors and teachers must prepare them with the 21st-century aptitudes requested in 4IR (Haviz and Maris, 2020). However, students will not be able to create these aptitudes on the off chance that the teachers themselves cannot prepare these skills for students (Shafie et al., 2019).

Teachers are experts in professional competence and must know the instructional method of educating as emphasized by Shulman (1986) within the system of Pedagogical Content Knowledge (PCK). While, in the 21st-century, science teachers need to have good knowledge in joining innovation and technology into teaching. Subsequently, they got to know about technology, as Mishra and Koehler (2006;2008) suggested as a framework for Technological Pedagogical Content Knowledge (TPACK). Recently, the methodology of teaching is no longer the same, as teaching needs have moved. To guarantee that students can create, hone, and apply 21st-century aptitudes, science instructors must have the information and competence to educate and prepare 21st-century skills.

TPACK describes essential knowledge for teachers within the millennial era to coordinate innovation within the education preparation (Zhang, 2011; Listiaji et al., 2020). It includes intuition between innovation, instructional method, and diverse substance, and this system emphasizes the intelligence between these three angles and other shapes of information (Koehler et al., 2014). The TPACK system expresses complex shapes of information and recognizes that instructors got to make lessons that advance technology-based learning. Whereas numerous TPACK considers are based on the introduction of giving birth to 21st- century learning (Mishra & Koehler, 2006; Angeli & Valanides, 2009; Koehler & Mishra, 2008), particular endeavors coordinated at advancing person 21st-century abilities may require assisting research (Valtonen et al., 2017). Particularly considering the current state of innovation and technology integration, by and large, underpins conventional and cutting-edge learning (Pringle et al., 2015). The perception of TPACK is also vital for teachers in Indonesia in the context of 21st-century learning. Teachers must have data information and implement Communication Technology (ICT) abilities to form meaningful learning since ICT gives opportunities for students to work collaboratively and autonomously concurring to the requests of 21st-century aptitudes. This is following the requests of teacher competency standards that require instructors or teachers to require advantage of information, communication, and innovative technology for self-development, particularly in communication strategy. The research results related to TPACK can moreover be utilized as a reference in efforts to adjust teacher pedagogical and professional competencies (Masrifah et al., 2018). TPACK is an essential part of 21st-century science learning achievement and learning achievement that students achieve in various domains and cannot be separated from the learning process (Juhji, 2020).

TPACK's framework to answer the challenges of the new era of learning also applies to the field of science education. In response to this mandate, science teachers have reestablished their endeavors to advance the integration of inquiry-based learning advances and hone into their instructing to improve students' understanding of science and way better get ready them for the 21st-century workforce (Pringle et al., 2015). With expanded openness to innovation, more science instructors are beginning to grasp its utilization as essential to outlining and fortifying science concepts, advancing student learning, and making strides in problem-solving and data examination (Slykhuis & Krall, 2011; Guzey & Roehrig, 2009). Thus, researchers want to conduct a literature study on how research trends are related to the TPACK topic, which is particularly useful for developing

teacher learning abilities in line with the 4.0 industrial revolution era, which uses a lot of technology integration in learning.

This review is focused on articles about TPACK. This study's main objective is to determine what consideration has been paid to TPACK research and analysis since 2010. The purpose of this review is also to find something that has not been researched regarding TPACK. This research consequently addresses the questions: (1) What topics from TPACK were the most and least researched? (2) What are the most cited articles regarding TPACK? (3) Who are the main contributors to the TPACK problem topic? (4) In which journals are the papers that analyze TPACK distributed most regularly?

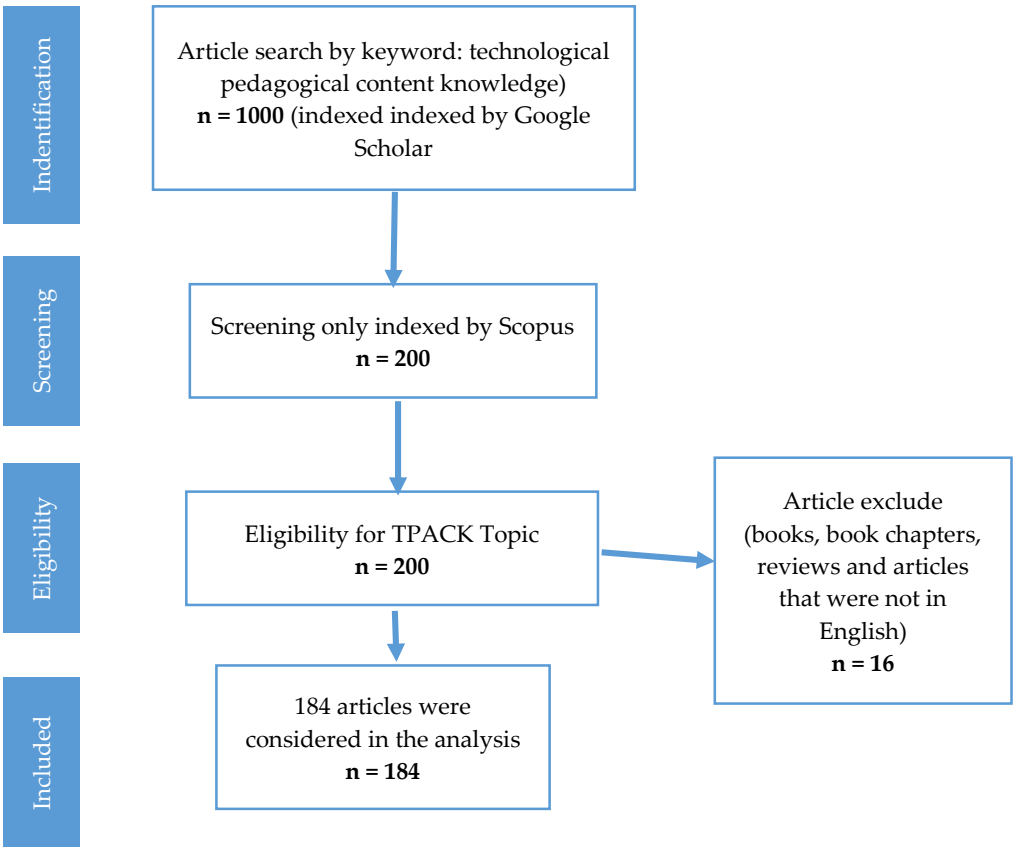
Methods

Research Strategy

The researcher chose not to select a concrete journal for investigation (Lee et al., 2009; Chang et al., 2010; Teo et al., 2014; Lin et al., 2014, 2013) to broaden the search and find the broadest possible picture. Search for articles was performed in a search engine by used Publish or Perrish software. The combination of keywords chosen was technological pedagogical content knowledge with publication periods between 2010 and 2020. The investigation was conducted on 12 October 2020. The search results obtained 1000 articles indexed by Google Scholar, only reputable international articles indexed by Scopus, in total 200 articles used in this study. The following selection is the language criteria. Out of 200 articles, 184 articles were considered for the subsequent analysis. The other 16 sources were excluded because they included books, book chapters, reviews, and articles not in English. The steps to search the article briefly shown in Figure 1.

Figure 1

The Diagram illustration of Finding Article



Selection of Articles

A total 184 of documents proceeded for forwarding analysis. In the forward step, the article's title and abstract were analyzed sequentially to exclude articles that did not fit the scope of this study. The number generated from 184 articles then analyzed thoroughly using *NVIVO 12+* software. Based on *NVIVO 12+* result showed the information about the word frequency that often (indicating the research topic) appears, topic words obtained that imply the map concept, the word cloud (indicating the most researched topic), and the general idea of each article obtained from abstract.

Research Location Analysis of TPACK

Data extraction of this study follows the illustration set from the SER literature review (Teo et al., 2014; Lin et al., 2014), which considers the study's geographic factor. In this study, the countries of the study which analyzed in this way; no provision should be used to measure the countries represented across the authors' team. (cp. Lin et al., 2014).

Research Topics Analysis

Research topics studied related to TPACK were obtained by analyzing word frequency using *NVIVO 12+* software. Researchers used words with at least five letters, then selected, and words associated with a combination of keywords: technological pedagogical content knowledge research was chosen. We selected only 14 words that occur most frequently by reducing non-research topics such as conjunctions. These 14 words are shown in Tabel 2. Furthermore, the most research topics and the least researched could be obtained.

Table 1

Word Frequency Results Using NVIVO 12+

Word	Length	Count
TPACK	5	45685
knowledge	9	31026
technology	10	28835
teachers	8	21072
content	7	20054
learning	8	17942
pedagogical	11	14576
teaching	8	14565
service	7	7558
educational	11	7473
development	11	6924
science	7	6775
mathematics	11	5481
integration	11	4768

The Most Referenced Article's Analysis

Researchers tabulated the citation data on Google Scholar to determine the most referred articles. The data then ranked based on the highest number of citations.

Main Contributor Analysis

The main contributor to TPACK's research was obtained by counting the most article writers and journals who contributed to publishing articles related to this field. Researchers use author and journal classification using Mendeley. After we have done the author classification in Mendeley, the next step is to sort the authors alphabetically. Then we counted how many articles each author wrote. The author with the highest number of articles is indicated as the primary contributor.

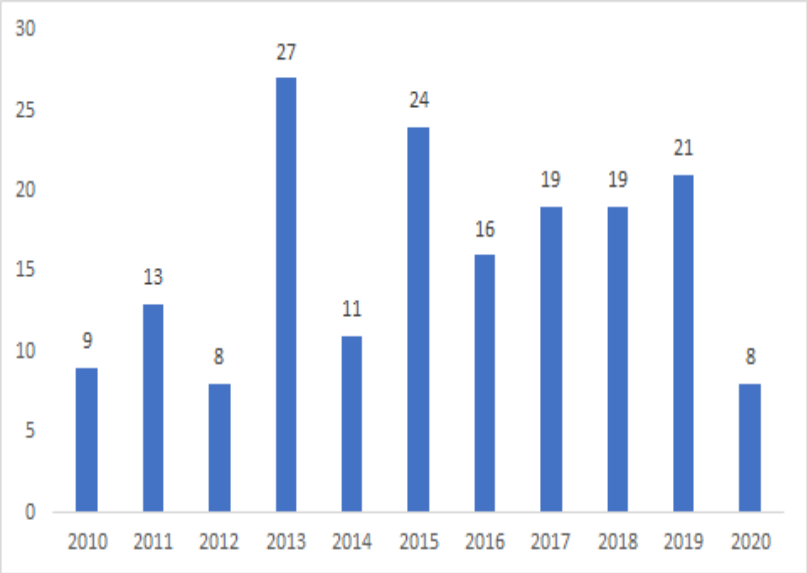
Findings and Discussion

Search Results and Article Selection

In this study, research articles focused on TPACK analysis were published periodically and indexed by Scopus between 2010 and 2020 (Figure 2). As seen in figure 1, research related to TPACK has fluctuated. Most articles used in this study were found in 2013 with 27 articles. This phenomenon is natural because 2013 was the beginning of the peak of the trend for developing the Industrial Revolution 4.0 worldwide, which in the previous year only developed in developed countries. A constant increase in the number of articles was seen from 2016 to 2019 and then fell back in 2020. This interesting fact shows that in 2020 there has not been much research on TPACK.

Figure 2

The Number of Scopus Indexed Articles Focused on TPACK's Research in 2010 to 2020



Research locations that discuss TPACK

Out of 184 articles were analysed, only 156 mentioned the country's location as the place for research on TPACK. The remaining 28 articles did not specify the research location, so we cannot define it. The location of the author's affiliation does not necessarily indicate the location of the research. From the article that mentions the location, most of the research was located in Asia, followed by Europe. The number of studies in Asia and Europe reached 63% out of 184 articles. More detailed data provided in table 2. Remarkably, the list of countries that have studied TPACK was shown in table 3 and table 4. In Asia, Taiwan was dominated, followed by Singapore and Indonesia.

Meanwhile, in Europe, Turkey was very dominant. In America, all research was conducted in the United States. In Australia and Africa, there were very few research articles related to TPACK. Of all the countries that studied TPACK, Turkey was the most dominated, followed by the United States.

Table 2

Number of Published Articles by Region

Territory	Number of Articles	Percentage (%)
Asia	65	35,33
Europe	51	27,72
America	29	15,76
Australia	6	3,26
Africa	5	2,72
Other (Not detected)	28	15,22

Table 3

Location of Countries that are Researching TPACK

Territory	Country
Asia	Saudi Arabia, China, Hong Kong, India, Indonesia, Kuwait, Malaysia, Singapore, Taiwan, Thailand,
Europe	Netherlands, Belgium, Cyprus, Estonia, Finland, Georgia, United Kingdom, Israel, Norway, Republic, Czech, Spain, Sweden, Turkey
America	United States of America
Australia	Australia, New Zealand
Africa	South Africa, Ethiopia, Ghana, Tanzania

Table 4

Distribution of the Number of Articles by Country

Country	Number of Articles	Percentage (%)
Turkey	34	18,5
America	27	14,7
Taiwan	17	9,2
Indonesia	13	7,1
Singapore	13	7,1
China	9	4,9
Australia	5	2,7
Malaysia	5	2,7
Cyprus	4	2,2
Hong Kong	3	1,6
Spanish	3	1,6
south Africa	2	1,1
Netherlands	2	1,1
Georgia	2	1,1
Norway	2	1,1

Sweden	2	1,1
Saudi Arabia	1	0,5
Belgium	1	0,5
Estonia	1	0,5
Ethiopia	1	0,5
Finland	1	0,5
Ghana	1	0,5
India	1	0,5
English	1	0,5
Kuwait	1	0,5
Israel	1	0,5
Czech Republic	1	0,5
Tanzania	1	0,5
Thailand	1	0,5
Other (Not detected)	28	15,2

Dominant Research Topic

Research topics studied related to TPACK were obtained by analysing word frequency using *NVIVO 12+* software. We selected only 14 words that occur most frequently, which criteria related to the TPACK topic. These 14 words indicate a research topic that is frequently researched. We explore the articles that contain and then look for ideas from the article as topic ideas from this topic. Figure 3. showed the words that appear more frequently in the articles that have been analyzed. The first word that often came up was TPACK because all the articles analyzed researched TPACK, so this word did not specifically indicate the research topic. Furthermore, the word Knowledge did not specifically indicate the topic of research because it was widely found in theoretical reviews of TPACK. Pedagogical, Technological, and Content are inseparable words from TPACK, so they also did not indicate a specific research topic.

The first topic that was widely researched was related to technology. This is natural because technology is at the core of the discovery of TPACK's ideas to answer the challenges of 21st-century learning that require information technology in learning. Research related to technology that has been carried out includes obstacles to the integration of information and communication technology in learning (de Freitas & Spangenberg, 2019), the influence of self-confidence regarding technology on the ability of prospective teacher TPACK (Abbitt, 2011; Hodges, 2018; Semiz & Ince, 2012; Oskay, 2017), the influence of technology courses on the development of TPACK abilities of prospective teachers (Hsu et al., 2014; Lee & Kim, 2017), development of technology-based assignments to develop TPACK (Polly & Orrill, 2012), motivation of prospective teachers to develop TPACK with an integrated technology education model (Holland & Piper, 2016), Integration of Science and Technology using the TPACK framework (Pringle et al., 2015), Computational thinking approach for prospective teachers in an effort to reorganize technology education (Mouza et al. , 2017), a description of the teacher's conception of technology in science inquiry learning (Mishra et al., 2019); technology mapping within the advancement of TPACK (Angeli & Valanides, 2013), the influence of TPACK on technology ethics (Kozikoglu & Babacan, 2019; Scheher et al., 2018), measurement of technological dimensions on TPACK (Scherer et al., 2017). However, as in the previous explanation, TPACK not only focuses on increasing technological knowledge, so TPACK's research only focuses on technological knowledge is still partial.

Figure 3

TPACK's Research Topics from 2010 to 2020, Based on the Frequency of Words that Often Appear.

The next topic that is interesting to research is the ability of pre-service and TPACK teachers. Most of the study focuses on measuring the TPACK ability (Giannakos et al., 2015; Horzum, 2013; Mouza et al., 2014; Cetin-Berber & Erdem, 2015; Urban et al., 2018; Vivian & Falkner, 2019). Based on the results of the TPACK subscale by Giannakos et al. (2015), Teachers declare that their Content Knowledge (CK) scale is sufficient, and Pedagogical Content Knowledge (PCK) needs to be developed. Moreover, further education exercise on how to elaborate innovation and technology in teaching was needed. The results of Horzum's (2013) research showed that technology courses and material development positively affect knowledge of technological pedagogical content (TPACK), prospective teachers' technological knowledge, and pedagogical knowledge of technology (TPK), and. This research was not considered the development on the pedagogical side. The findings of Mouza et al. (2014) implied that contributors experienced critical picks up in all TPACK developments. These results have suggestions for educators and researchers inquisitive about developing and assessing candidates' knowledge about teaching with technology because the measurement results indicate that the teacher candidates' TPACK ability is not yet adequate. Cetin-Berber and Erdem (2015) try to measure the TPACK ability of prospective teachers separately, namely by measuring Pedagogical Knowledge (PK), Content Knowledge (CK), and Technological Knowledge (TK). The results showed that CK and PK primarily contributed to the development of TPACK for pre-service teachers (Redmond and Lock, 2019), whereas TK was not a critical indicator. These studies imply that most of the results indicated that the ability of TPACK for prospective teachers was still not good, especially in the aspect of Technological Knowledge (TK). In the previous explanation, TPACK not only focuses on increasing technological knowledge, so TPACK's research only focuses on technological knowledge is still partial.

Research on the implementation of TPACK Teachers' abilities in learning (teaching and learning) was conducted by Abera (2014) by applying the TPACK framework to English Teachers in Ethiopia also Tajudin and Kadir (2014) studied the practice of teaching mathematics using TPACK. The development of the TPACK model has been carried out by Chai et al. (2011, 2013) for elementary school teachers. The results implied that the positive influence of the basic knowledge factor model Pedagogical Knowledge (PK), Content Knowledge (CK), and Technological Knowledge (TK) was not directly related to the second layer knowledge factor model that has been integrated with Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), and Technological Pedagogical Knowledge (TPK). This indicates that the strengthening of TPACK's ability separately is not positively correlated with TPACK's overall ability. In addition, other factors that affect the ability of TPACK teachers have also been researched, namely self-confidence (Abbitt, 2011; Hodges, 2018; Semiz & Ince, 2012; Oskay, 2017), motivation (Holland & Piper, 2014; 2016), and behavior (Kozikoglu & Babacan, 2019; Scheher et al., 2017). Moreover, Alayyar et al. (2012) stated the findings of their study on the

development of the TPACK framework supported by Blended Learning. The results showed that with the Blended Learning intervention, science teacher candidates would more easily integrate ICT into their teaching practices in the future.

In particular, research has also been carried out related to the TPACK ability of teachers and science teacher candidates, although the number is still minimal. Kafyulilo et al. (2015) conducted research related to information technology in science and mathematics teacher education to develop TPACK abilities. The results showed that science teacher candidates had adequate information of substance and pedagogical knowledge but were restricted to the technology-related knowledge components of TPACK. Moreover, Canbazoglu et al. (2016) showed that a science method course that focuses on TPACK impacts the TPACK of science teacher candidates. These courses help teachers elaborate their knowledge about the effective use of educational technology tools. Mishra et al. (2019) examined the teacher's conception of technology in authentic science inquiry using TPACK. The results indicated that science teachers need information about the latest trends in modern research and technology and require training to bring similar research into their classrooms. Kartal and Afacan (2017) examined the Pedagogical Content Knowledge of Turkish Pre-service Science Teachers (TPACK) based on demographic variables. The demographic variable is that the TPACK level of pre-service science teachers develops in proportion to their grade level. These findings support the idea that technology and teaching elaboration have a positive impact on TPACK. Irmita and Atun (2018) also researched the Technological Pedagogical and Content Knowledge (TPACK) approach on students' scientific literacy and social skills. The five studies above are only at the stage of measuring TPACK for Science Teachers' ability and one study on the application of TPACK in science learning so that research is still needed to increase the ability of TPACK for Science Teachers.

Furthermore, the research raised the topic of TPACK integration, including Abbitt (2011) and Semiz and Ince (2012), which examined the relationship of teacher confidence in technology integration to TPACK abilities. Of course, this research has not answered the idea of integration because what is being studied is only integrating technology in learning. Moreover, Holland and Piper (2016) have developed a technology integration education model for prospective teachers to increase TPACK's ability. However, the measurement only reaches the level of teacher motivation in the technology integration model. In another study, De Freitas and Spangenberg (2019) examined teachers' barriers related to technology integration in learning. Six main obstacles were found in integrating ICT in the classroom, namely time constraints related to curriculum, technology infrastructure, the impact of using ICTs on the learning process, teacher pedagogical beliefs, ineffective professional development, and bad leadership. The author sees that there is no research that integrates all components of TPACK. This topic will be interesting to be raised in future research.

Most Referenced Articles

Citation search results using Google Scholar indexation get TPACK research articles widely referenced (Table 5). Only the top 10 articles are listed as most references articles and we add the remaining 174 articles to the information at the bottom, namely articles with less than 400 citations. The methodology used was adopted from Lee et al. (2009); namely, the articles with the highest number of citations are considered the most influential in TPACK research.

Table 5

Articles with the Most Citations According to Google Scholar

Author	Article Title	Number of Citations	Year
Koehler, Matthew J., Mishra., Cain, William.	What is Technological Pedagogical Content Knowledge (TPACK)?	3805	2013
Graham, Charles R.	Theoretical considerations for understanding technological pedagogical content knowledge (TPACK)	738	2011
Voogt, J., Fisser, P., Pareja Roblin, N., Tondeur, J., Van Braak, J.	Technological pedagogical content knowledge - A review of the literature	722	2013
Chai, Ching Sing., Koh, Joyce Hwee Ling., Tsai, Chin Chung.	Facilitating preservice teachers' development of technological, pedagogical, and content knowledge (TPACK)	699	2010
Harris, Judith B., Hofer, Mark J.	Technological pedagogical content knowledge (TPACK) in action: A descriptive study of secondary teachers' curriculum-based, technology-related instructional planning	648	2011
Lee, Min Hsien., Tsai, Chin Chung.	Exploring teachers' perceived self-efficacy and technological pedagogical content knowledge with respect to educational use of the World Wide Web	626	2010
Archambault, Leanna M., Barnett, Joshua H.	Revisiting technological pedagogical content knowledge: Exploring the TPACK framework	618	2010
Chai, Ching Sing., Koh, Joyce Hwee Ling., Tsai, Chin Chung.	A review of technological pedagogical content knowledge	594	2013
Koh, Joyce Hwee Ling., Sing, Chai Ching.	Modeling primary school pre-service teachers' Technological Pedagogical Content Knowledge (TPACK) for meaningful learning with information and communication technology (ICT)	497	2011
Abbitt, Jason T.	An Investigation of the Relationship between Self-Efficacy Beliefs about Technology Integration and Technological Pedagogical Content Knowledge (TPACK) among Preservice Teachers	464	2011
Other articles (174)	-	Less than 400 citations for each article	

It can be seen that the articles by Koehler et al. (2014) are mostly referenced, leaving other articles behind. When viewed from the article's contents, this article represents a theoretical article about TPACK, so it is clear that it is definitely referred to by almost a large part of TPACK researchers.

Similar theoretical articles are also referred to quite a lot, namely Archambault and Barnett (2011), Graham (2011), and Koehler et al. (2014). Articles with the TPACK literature review model are also widely referred to, namely Voogt et al. (2013) and Chai (2013). Furthermore, articles in the form of experimental research that are widely referred to are Chai et al. (2011) with the topic of developing TPACK for prospective teachers, Lee et al. (2019), and Abbitt (2011) about teacher confidence and prospective teachers towards TPACK. The descriptive research was conducted by Harris and Hofer (2011) regarding learning-related technology based on the secondary teacher curriculum. Moreover, the last article that many referenced has a topic about reviewing the methods and instruments of measuring TPACK for prospective teachers (Abbit, 2011).

The Main Contributor

Researchers found 714 authors who contributed to TPACK's research. From the number of authors, a ranking is then carried out to find out whom the authors deserve to be called the main contributors in this field. Researchers only present authors with two articles and more because the other authors only contribute to 1 article. The data is presented in Table 5.

Table 6

Author with the Most Article Contributions from 2010 – 2020

Author	Number of Articles	Affiliates
Chai, Ching Sing	22	National Institute of Education, Nanyang Technological University, Singapore
Koh, Joyce Hwee Ling	16	National Institute of Education, Nanyang Technological University, Singapore
Tsai, Chin Chung	11	National Taiwan University of Science and Technology, Taiwan Chin-Chung
Angeli, Charoula	6	Department of Education, University of Cyprus
Mouza, Chrystalla	6	School of Education, University of Delawar
Tondeur, Jo	6	University of Ghent, Ghent, Belgium
Karchmer-Klein, Rachel	5	University of Delaware
Jason T. Abbitt	2	Miami University
Other authors (110 articles written by 706 authors	each author contributed to 1 article	

Based on Table 5, the most productive writers in this field are Chai, Ching Sing, and Koh, Joyce Hwee Ling. Both have the same affiliation: the National Institute of Education, Nanyang Technological University (NTU), Singapore. This result implies that NTU is very concerned about research related to TPACK. The interest in the study topic raised from 7 main contributors in TPACK includes strengthening teacher candidates related to TPACK, teacher perceptions of TPACK, technology mapping on TPACK, assessment on TPACK, and testing of factor structures and invariance measurement of technological dimensions.

Journals That Have published TPACK research

Another essential factor that can offer assistance for researchers adjust to TPACK is which journals publish TPACK research. The results of this analysis only show 17 journals containing two or more research articles and 86 other journals only publish 1 article (Table 7.).

Table 7

Scientific Journal With the Largest Number of Articles on TPACK Research

Journal	Number of Articles
Australian Educational Computing	14
Computers and Education	12
Journal of Educational Computing Research	12
Journal of Research on Technology in Education	9
Educational Technology Research and Development	7
Asia-Pacific Education Researcher	5
Journal of Physics: Conference Series	5
British Journal of Educational Technology	4
Computer-Assisted Language Learning	4
Education and Information Technologies	4
Egitim ve Bilim	4
Journal of Digital Learning in Teacher Education	4
Eurasia Journal of Mathematics, Science and Technology Education	3
International Journal of Emerging Technologies in Learning	3
Journal of Computer Assisted Learning	3
Procedia - Social and Behavioral Sciences	3
Journal of Turkish Science Education	2
Other Jornal (86 Journals, 86 Articles)	1 article for each journal

The results showed that articles related to TPACK's research were published mostly in technology-based educational research-oriented journals. This result is in line with the TPACK framework, which makes technology integration in learning an essential skill for teachers in 21st-century learning (Mishra & Koehler, 2006). An impressive result is that there are still a few journals based on science education research that publish articles on TPACK. This result can be observed in Table 6**.** that journals based on science education research are ranked 13th, 15th, and 16th. Even though many articles related to TPACK in science education have been published in the other journal. This shows that not many authors have published TPACK articles on science education in the journals based on science education.

Conclusion and Implications

Many educational researchers have paid attention to the topic for the period 2010-2020. This result is in line with the need for TPACK's ability to face the 21st-century education trend relying heavily on the integration of technology in science learning. Asia and Europe are the largest TPACK research locations, followed by America. The countries with the most TPACK research areas are Turkey and the United States. Another interesting fact is that the researchers who published many articles about TPACK did not come from these two countries but Singapore. The most prolific writers in this field are Chai, Ching Sing, and Koh, Joyce Hwee Ling. Both have the same affiliation: the National Institute of Education, Nanyang Technological University (NTU), Singapore.

Furthermore, the journal analysis shows that articles related to TPACK's research are published mostly in technology-based educational research-oriented journals. This result aligns with the TPACK framework, which makes technology integration in learning an essential skill for teachers in 21st-century learning. An interesting result is that there are still a few journals based on science education research that publish articles on the topic of TPACK.

The analysis of topics related to TPACK shows that the most researched topics on the components of knowledge in TPACK are Knowledge, Technology, Content, and Pedagogical. Furthermore, related to learning, there are topics of teaching, learning, and education. There are teachers and pre-service teachers and topics related to mathematics and science topics related to the subject. The least researched is development and integration, which means that these two topics have not been of interest to researchers in the last ten years.

From several analyses of this literature review, it is hoped that it will make it easier for researchers interested in TPACK research, especially TPACK in science education, to find appropriate and various references and reference centers and formulate what topics need to be researched for further research.

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