Science Education Research within TPACK Framework at a Glance: A Bibliometric Analysis

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Article Info

Abstract

We conducted a bibliometric analysis of the scientific articles in the field of science education research within TPACK framework published between 2012 and 2021. In total, 910 articles published in science education and technological education journals were extracted from Scopus databases. This study aims to present a summary of science education research within TPACK framework regarding number of annual production, most influencing authors and productive countries, the co-authorship collaboration, and research foci. The main findings show that the number of articles on science education research within TPACK framework throughout the period 2012 to 2021 fluctuated. Co-authorship collaborations were mostly made up of researchers from the same country. Furthermore, a shift in the research foci was observed. Recent research foci have emphasized higher education, self-efficacy, and STEM as important keywords. In addition, one of the most common articles published in the field is a literature review.

Introduction

Education is one of the most active uses of technology nowadays. As a result, debates over whether or not technology should be included in education are issues of the past, and research is now being conducted on how it should be integrated in learning process in the most practical, effective, and beneficial way (Koyuncuoglu, 2021). In addition, educators agree that technology cannot be treated as a separate body of knowledge distinct from the pedagogical and content knowledge required by teachers (Wang, Schmidt-Crawford & Jin, 2018) since the use of technology in learning environments is closely related to students' learning achievement (Angeli & Valanides, 2009; Kopcha, 2010).

To address this issue, Mishra & Koehler (2006) introduced a conceptual framework called as Technological Pedagogical Content Knowledge (TPACK) for comprehending teacher knowledge required for technology integration. TPACK developed from Shulman's (1986) theory of pedagogical content knowledge (PCK) and focuses on teachers' need to proficiently establish their capability in integrating technology within content and pedagogical domain constructs. TPACK is a beneficial conceptual framework for thinking, examining, and evaluating aspects that teachers need to know in order to incorporate technology into their classroom, nonetheless it should ultimately be understood as a structure for how teachers can develop this unified constructs (Baran,

Chuang, & Thompson, 2011). In summary, this framework demonstrates that in the digital age, constructive teaching and learning must emphasize the complex interaction of content, pedagogy, and technological knowledge (Willermark, 2018).

Literature related TPACK is very beneficial for preparing teachers to integrate technology in learning process. The researchers in science education have utilized TPACK framework to

- assess pre- and/or in- service science teacher's TPACK knowledge (e.g., Alrwaished, Alkandari, & Alhashem, 2017; Voithofer, et al., 2019; Koyuncuoğlu, 2021; Ramnarain, Pieters, & Wu, 2021),
- examine pre- and in- service science teacher professional development (e.g., Irmak & Tüzün, 2018; Rochintaniawati et al., 2019; Chai, Rahmawati, & Jong, 2020; Juanda, Shidiq, & Nasrudin, 2021),
- develop and validate TPACK instrument (e.g., Akman & Güven, 2015; Sahin, 2011; Valtonen et al., 2017; Wilujeng, Tadeko, & Dwandaru, 2020),
- explore relationship between TPACK and other predictors (e.g., Kaleli, 2021; Kara, 2021; Lau, 2018; Wright & Akgunduz, 2018; Voithofer et al., 2019),
- implement TPACK-related learning and investigate its effect (e.g., Dorfman et al., 2019; Oda, Herman & Hasan, 2019; Tanak, 2020; Pondee, Panjaburee & Srisawasdi, 2021), and
- provide materials in supporting teacher education program (e.g., Alrwaished, Alkandari, & Alhashem, 2017; Baran et al., 2019; Walan, 2020).

As a result, presenting an overview of current research output in science education within TPACK framework field has become an important task. To best of my knowledge, bibliometric analysis of TPACK literature is not limited to science education field, but it involve multidisciplinary field (e.g Ye, Chen, & Kong, 2019; Soler-Costa et al., 2021; Lee, Chung, & Wei, 2022; Zou et al., 2022). This prompted us to perform a bibliometric analysis in order to create the summary of the current state of the literature in the last decade. The findings of this study will be beneficial to direct the future studies regarding TPACK in science education.

Method

A few years ago, scientific literature collection and quantitative analysis were conducted manually (Aljuaid et al., 2021). Then, the rapid advancement of information technology in the 21st century leads into the enhancement in data processing (Chen, Ibekwe-Sanjuan, & Hou, 2010). Following this, in recent years, bibliometric analysis has grown in popularity in educational studies. Science education field, particularly, use this method to discuss some issues such as classroom dialogue (Song et al., 2019), online formative assessment in higher education (Sudakova et al., 2022), scientific literacy (Effendi et al., 2021), e-learning (Sweileh, 2021), STE(A)M (Özkaya, 2019; Marín et al., 2021), or internet of things in education (Dai et al., 2021) were—among others— bibliometrically analysed. That occurs because bibliometric analysis helps to (1) identify and map collective scientific research topics and (2) provide a comprehensive summary of scientific outcomes and their growth in the field of study investigated over time (Donthu et al., 2021). In this study, we adapted the protocol for science mapping recommended by Aria & Curccurullo (2017) as presented in Figure 1.
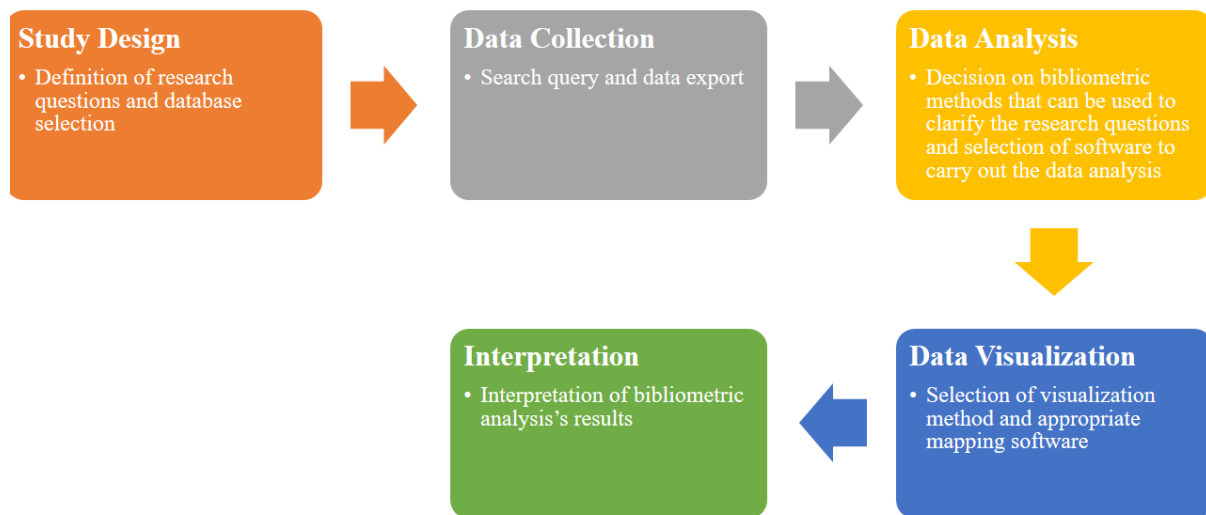
Figure 1. Protocol for Conducting the Science Mapping using Bibliometric Analysis

Study Design

We accessed Scopus (http://www.scopus. com) on June 6th 2022 to obtain the bibliometric data. Scopus is among the most important bibliographic database and has been widely acknowledged as source for bibliometric data in previous studies (Cobo et al., 2011). To guide the bibliometric study, we pose the research questions as follow:

1. How have the publications and articles citation on science education research within TPACK framework developed over time from 2012 to 2021?
2. Who were the most influencing authors and countries in the publication of articles on science education research within TPACK framework from 2012 to 2021?
3. Is there evidence of widespread collaboration among researchers in science education research within TPACK framework from 2012 to 2021?
4. What were the most relevant keywords, and what co-occurrence patterns can be found in science education research within TPACK framework from 2012 to 2021?

Data Collection

We collected the data in June 2022. For the search query, a set of data-related common criteria has been established, which includes the use of keywords in conjunction with binary operators such as OR and AND. We selected technological pedagogical content knowledge OR pedagogical content knowledge OR TPACK AND science as keywords for data collection and filtered article titles, article abstracts and the authors' keywords. Furthermore, we limited our data collection to studies published between 2012 and 2021 and articles published in peer-reviewed journals. The data from Scopus were exported in .csv format and proceed by using the R-package bibliometrix.

Table 1 presents an overview of the data used for the recent study.

Table 1. A Summary of the Data extracted from Scopus Databases and used in the Bibliometric Analysis

Output	Results
Data primary information	
Duration	2012-2021
Number of sources	348
Number of documents	910
Average years from publication	5
Average citations per document	11.79
Average citations per year per document	1.769
Total number of references (without duplicates)	41672
Total number of author keywords	2273
Authors	
Number of authors	2315
Number of authors of singled-authored documents	162
Number of authors of multi-authored documents	2153
Authors collaboration	
Number of single-authored documents	170
Authors per document	2.54
Co-authors per document	2.97
Collaboration index	2.91

Data Analysis and Visualization

There are two major methods of bibliometric analysis: (1) performance analysis and (2) science mapping (Donthu et al., 2021). The goal of performance analysis is to evaluate the scientific outcome in a set research field using qualitative and quantitative indicators, associated with the general scientific community and specific different researchers (Gutiérrez-Salcedo et al., 2018). Science mapping describes the connections between numerous subject areas, documents, or authors in a spatial format (Small, 1999). In light of this, we utilized both performance analysis and science mapping methods to answer the research questions. In addition, R package bibliometrix was utilized to perform the bibliometric analysis, meanwhile we utilized VOSviewer to visualize the science mapping results. Figure 2 shows a complete summary of the data analysis performed as well as the software analysis tool.
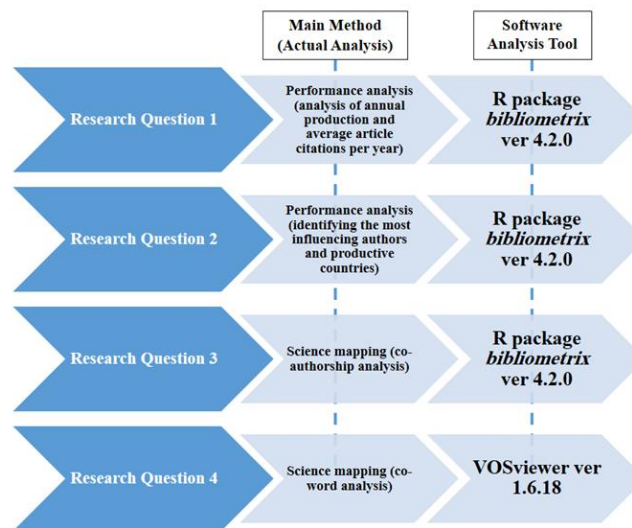

Figure 2. Summary of Data Analysis and Software Analysis Tools utilized

Results

Development of the Scientific Output on TPACK Framework in Science Education Research

Figure 2 presents the development of science education researches within TPACK framework over the time. During the period 2012 and 2021, the number of articles fluctuated. The fewest article production occurred in 2012 (n = 70) and 2014 (n = 62). The highest increasing of article productions emerged in 2019 with a total of 100 articles. Then, the number of article is slowly increasing in the last two years, with a total of 124 and 127 articles produced, respectively.
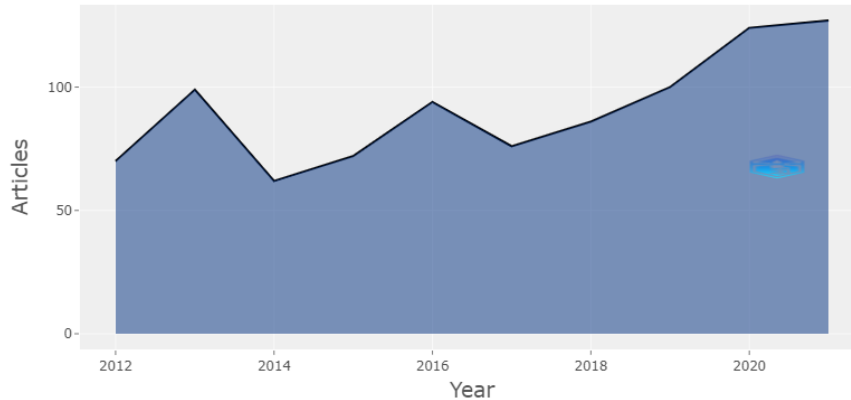

Figure 3. Annual Scientific Production

Of the 2315 authors counted within the documents, 196 published at least two articles on TPACK framework recorded in Scopus in the period 2012-2021. Furthermore, 29 authors published three articles, 18 published four articles, and 14 published five or more articles. In other words, the vast majority of authors only published one article during this time period. Each published article was cited 11.79 times on average. Each publication received approximately 1.769 citations per year on average. Figure 4 depicts the average number of article citations per year.
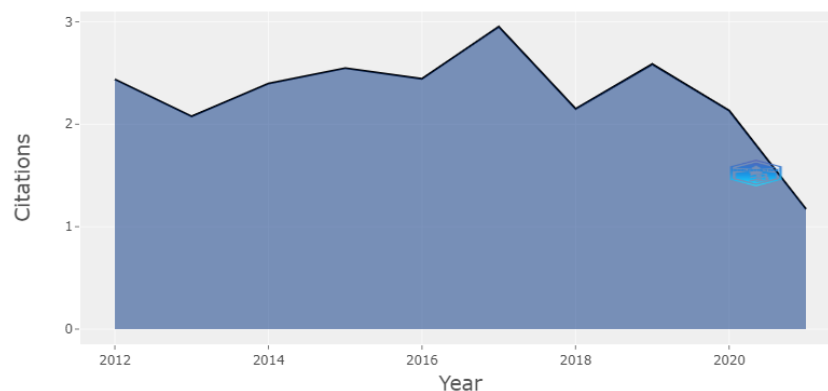

Figure 4. Average Article Citations per Year

The Most Influencing Researchers and Countries Publishing Articles on TPACK Framework in Science Education Research

The authors further analyzed the most influencing researchers employing TPACK framework in science education

studies regarding the total citation between 2012 and 2021 as shown in Table 3. It can be found that Voogt J has the highest total citation. Furthermore, Chai CS has two articles cited the most. In addition, the documents with top citation were dominantly published in period 2012-2013.

Table 3. Top 10 most influencing authors employed TPACK framework in science education research

Corresponding Author	Publication Year	Journal	TC	TCpY	Doi
VOOGT J	2016	J Educ Techno Soc	167	23,857	-
PARK S	2012	J Res Sci Teach	154	14	10.1002/tea.21022
NILSSON P	2012	J Sci Teacher Educ	131	11,909	10.1007/s10972-011-9239-y
JANG S-J	2012	Comput Educ	124	11,273	10.1016/j.compedu.2012.02.003
CHAI CS	2013	J Sci Educ Technol	113	11,3	10.1007/s10956-012-9396-6
CHAI CS	2013	Instr. Sci.	87	8,7	10.1007/s11251-012-9249-y
ROLLNICK M	2013	Afr. J. Res. Math. Sci. Technol. Educ.	69	6,9	10.1080/10288457.2013.828406
MAVHUNGA E	2013	Afr. J. Res. Math. Sci. Technol. Educ.	69	6,9	10.1080/10288457.2013.828406
JANG S-J	2013	Australas. J. Educ. Technol.	64	6,4	10.14742/ajet.282
PARK S	2013	Educ. Assess. Eval. Account.	63	6,3	10.1007/s11092-013-9157-y

Note: TC = Total Citation; TCpY = Total Citation per Year

Among the most productive authors, it is detected that Park S and Voogt J have mostly published to the field over the last decade. On the other hand, others appear to have published all of their works in a shorter period of time. Aydin S only published the articles in the period 2013-2015. Some researchers have not published any articles since 2018 yet. Figure 5 details the authors' production during 2012-2021.
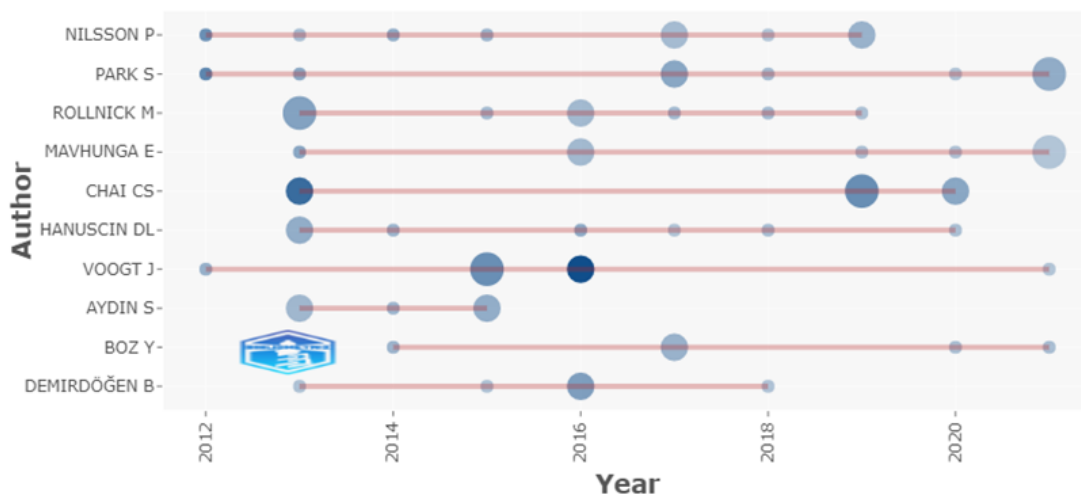

Figure 5. Top Authors' Production over the Time

Because the total citation in Table 3 includes citations from outside the TPACK research area, it is essential to recognize the most significant articles for the TPACK in science education research community by examining how many times a given article in our dataset was cited by other authors from the same collection. This is called as total local citations. Table 4 lists the top ten documents with the highest local citations.

Table 4. Top ten most cited documents published in period 2012 – 2021

Corresponding Author	Publication Year	Name of Journal	LCS	GCS	Doi
Park S	2012	J Res Sci Teach	64	154	10.1002/tea.21022
Nilsson P	2012	J Sci Teach Educ	28	131	10.1007/s10972-011-9239-y
Sadler Pm	2013	Am Educ Res J	24	165	10.3102/0002831213477680
Lin T-C	2013	J Sci Educ Technol	20	113	10.1007/s10956-012-9396-6
Brown P	2013	J Sci Teach Educ	20	49	10.1007/s10972-012-9312-1
Mavhunga E	2013	Af J Res Math Technol Educ	18	69	10.1080/10288457.2013.828406
Jang S-J	2012	Comput Educ	15	124	10.1016/j.compedu.2012.02.003
Faikhamta C	2013	RES SCI EDUC-A	14	40	10.1007/s11165-012-9283-4
Aydin S	2015	Teach Teach Educ	13	35	10.1016/j.tate.2014.10.008
Hanuscin Dl	2013	J Sci Teach Edu	13	44	10.1007/s10972-013-9341-4

Note: GCS = Global Citations; LCS = Local Citations

In order to provide a summary of the countries contributing to the scientific discussion about the TPACK framework in science education research, we explored the corresponding authors' countries, followed by the total of single and multiple country publications. The findings are presented in Figure 6.
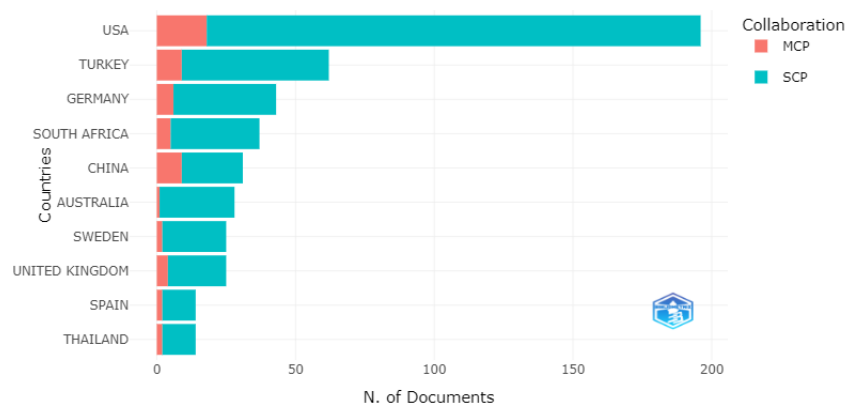

Figure 6. Corresponding Author's Country

Based on Figure 6, it can be seen that the top ten consist of countries from all continents. Surprisingly, South Africa emerged in fourth position. It supports Table 3 that presents two influencing authors from South Africa. In other words, TPACK framework have been employed predominantly by many authors from wide-ranging regions in science education field. The majority of TPACK publications, in particular, were written by corresponding authors from the United States (n = 196 articles), followed by Turkey (n = 62 articles) and Germany (n = 43 articles). Furthermore, the percentage of multiple country publication from USA was only 9.18%. On the other hand, China has biggest percentage of multiple country publications (29.03%) followed by United Kingdom (16.00%) and Turkey (14.52%).

Collaborations among Researchers in the Fields

Research collaboration have significant role in scientific productivity (Lee & Bozeman, 2005), promoting knowledge construction, and academic quality (Rigby & Edler, 2005) in modern science. Not all practises of research collaboration are officially recorded in articles (Melin & Persson, 1996). Still, the number of joint publications may inform an indicator of academic collaboration among researchers (Tijssen, 2011) since they are clearly correlated (Glänzel & Schubert, 2010). As a result, we carried out a co-authorship analysis to determine collaboration among science education researchers in the TPACK community. Figure 6 depicts the end result. In the clustering criteria, we restricted authors to at least two joint publications. In other words, authors with single-authored articles are not included in the visualization.
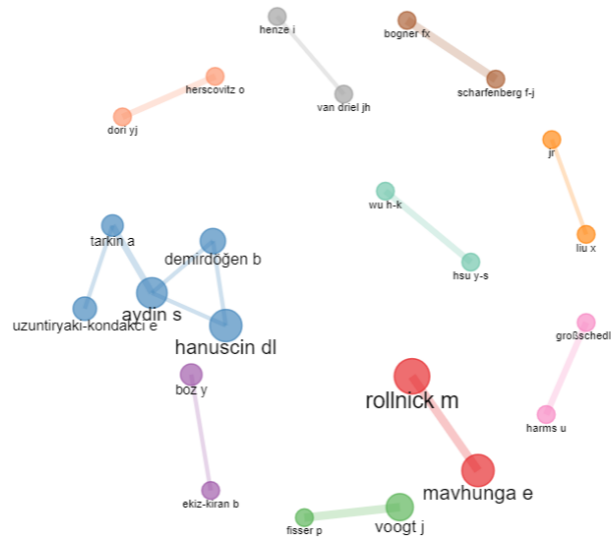
Figure 6. Co-authorship Network of Science Education within TPACK Researchers publishing from 2012 to 2021

Figure 6 shows that there are several prominent disjoint clusters comprised of a few authors. The clusters are even mostly dominated with collaborations between two authors. Only blue cluster which consists of five authors. This leads to evidence that there have been some collaborations among TPACK researchers in the field of science education. Still, there is no authors in one cluster who have extensive collaboration with author from the other cluster. For more clear description, Table 5 focuses on the individual cluster analysis. Based on Table 5, the

individuals cluster mostly consist of author from the same country. This highpoints the evidence that only a small number of international collaborations occurred among science education researcher in period 2012-2021. Table 5 supports the results presented by Figure 4.

Table 5. Exemplary National and International Collaboration among Researchers on TPACK

Clusters	Authors (Country)	Exemplary Publication
Blue	Aydin, Demirdogen, Hanuscin, Tarkin, Azuntiryaki-kondakti (Turkey)	Aydin et al. (2015)
Red	Mavhunga, Rollnick (South Africa)	Malcolm, Mavhunga, & Rollnick (2019)
Green	Fisser, Voogt (Netherlands)	Kafyulilo, Fisser, & Voogt (2016)
Yellow	Liu, Jr (USA)	Yang et al. (2020)
Orange	Dori, Herscovitz (Israel)	Avargil, Herscovitz, & Dori (2013)
Purple	Boz, Ekiz-kiran (Turkey)	Ekiz-Kiran, Boz, & Oztay (2021)
Pink	Harms, Großschedl (Germany)	Großschedl, Welter, & Harms (2019
Grey	Henze (Netherlands), Van driel (Netherlands & Australia)	Vossen et al. (2020)
Aqua	Hsu, Wu (Taiwan)	Yeh et al. (2017)
Brown	Bogner, Scharfenberg (Germany)	Scharfenberg & Bogner (2021)

Keyword Co-Occurrence Patterns in Science Education Research within TPACK Framework

According to a frequency analysis, the most frequently authors' keywords in their articles were pedagogical content knowledge (200 times), science education (58 times), and professional development (56 times). These keywords are still general and neither inform us to the major research themes in the field nor trace how they have shifted over time. As a result, we carried out a co-word analysis to reveal co-occurrence configurations, which allowed us to gain deeper perspectives, because the co-word analysis method investigated the actual content of the publication itself (Donthu et al., 2021). In other words, the assumption underlying a co-word analysis is that there is a thematic relationship between keywords when they appear frequently together.

The results of co-word analysis were visualized using VOSviewer software. In order to obtain complete data, we included terms derived from article titles, abstracts, and author keywords in the co-words analysis. However, for the co-word analysis, we only include terms that appeared in at least five articles. Of the 2775 keywords, 89 met the threshold. Then, we manually omitted several keywords (teacher, teaching, learning, design, education, etc) which have low relevance value and obtain no additional content. We also removed some keywords that have same meaning. As results, 72 keywords remained for mapping. The complete co-word network is visualized in Figure 7.

In Figure 7, the font size represents the relative frequency of term occurrences, and connecting lines represent keyword co-occurrence. Term clusters that appear repeatedly are highlighted in the same color. The co-word analysis reveals numerous clusters that are not mutually exclusive. The red and blue are two major clusters which

influence the most other clusters in the mapping since both clusters have the biggest total link strengths. The blue cluster is the biggest cluster which consist of ten keywords, such as content knowledge, pedagogical knowledge, pedagogical content knowledge, science teacher education, teacher preparation, etc. Meanwhile, the red cluster is the cluster which consists of the most keywords (n=12), such as professional development, science education, mathematics education, nature of science, pre service teachers, self-efficacy, etc. Yet, the red cluster does not have both occurrence and link strength as high as the blue one. Apart from that, both these primary clusters link to mostly other clusters and indicate the interdependency of these two pillars. On other hand, these two clusters also lead us to recognize two main pillars of TPACK framework in science education researches.
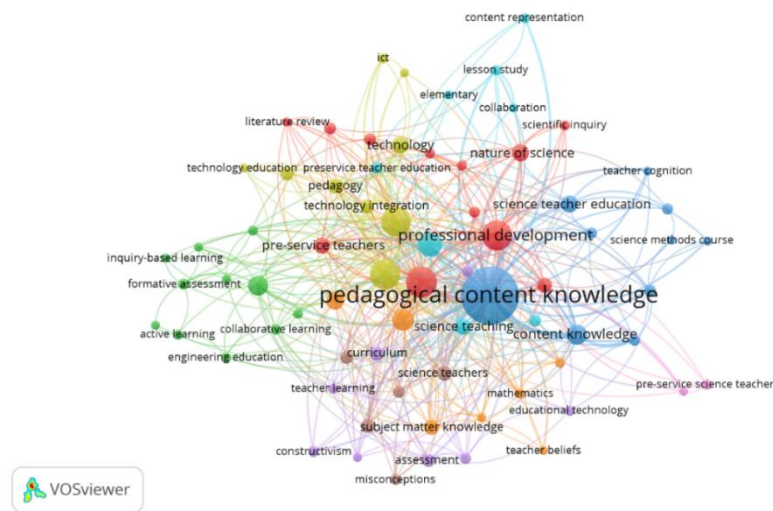

Figure 7. Final Visualization of the Co-word Analysis

Surprisingly, the green cluster appears on the second position in context of number of terms (n=11), but this cluster has the lower link strength than the blue one. The green cluster generally informs us the specific domain of the research. Lastly, in the more thoroughly looks, we found six clusters else which comprise fewer keywords, namely active learning, argumentation, lesson plan action research, and self-efficacy belief which link to pedagogical content knowledge and/ or professional development. The co-words analysis for TPACK framework within science education research concluded that each cluster does not inform us specific theme since it comprises different features of TPACK framework as earlier mentioned for red, blue, or green cluster. It indicates that TPACK framework has been widely employed to examine various teachers' professional development from different subject in science. Particularly, the field has measured pre- or in- service science teachers' TPACK knowledge with several methods, for example lesson study as emerged in the visualization.

By converting Figure 7 into an overlay visualization, we can further investigate the sequential shift of the TPACK framework within the science education research theme. Based on the publication years of the articles, the VOSviewer software calculates the average publication year, which is then linearly transformed into a scale ranging from 0 to 1. Colors are used to represent the scale. Figure 8 shows the overlay visualization.

Figure 8 shows a shift on the main focus of TPACK research over the average years. Majority of the keywords,

the primary ones in particular, were in the old under investigation year. Some focuses of TPACK researches have not studied in the present years, while other are still under examined. For subject and subject matter, biology, nature of science, mathematics, computer science, engineering education are included in past research cluster (average year about 2016) and hardly examined in the recent years. For instructional context, collaborative learning, inquiry based learning have average year about 2015 and rarely contributed in recent TPACK researches. Meanwhile, active learning have average year around 2018.
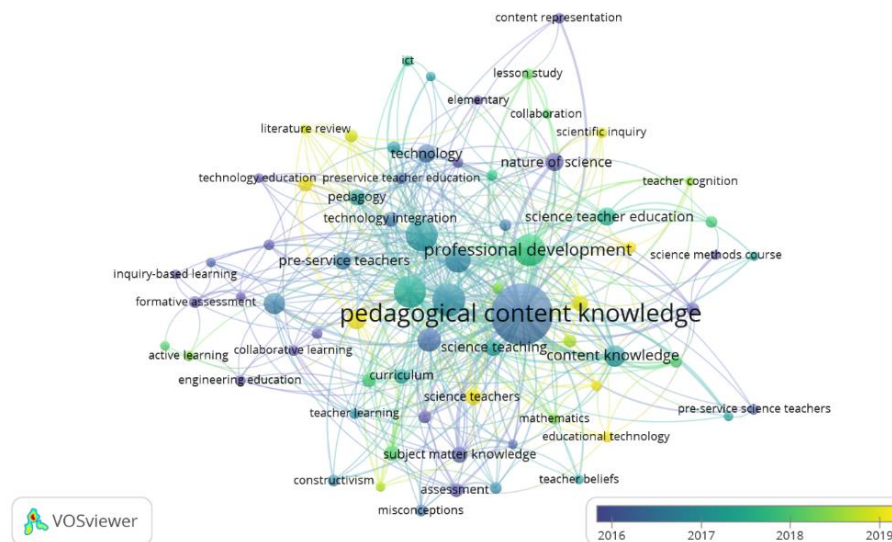

Figure 8. Overlay Visualization of the Co-word Analysis Results

In terms of teachers' professional development examined, teachers belief, teachers knowledge, self-efficacy belief were frequently examined in old publication since they have average year around 2016. In contrast, self-efficacy itself has average year around 2019. This means TPACK framework has employed to investigate pre- or in-service science teachers lastly. Figure 8 also informs that literature review has loaded the field in recent years, meanwhile action research, qualitative research, and structural equation modelling were frequently used in past researches. It is also seen that higher education and STEM are keywords that frequently emerge in recent years.

Discussion and Conclusion

We summarize the main findings of the research questions, followed by a discussion about the possible directions for future TPACK research in science education field:

- Answer on research question 1: annual article production fluctuated in the period 2012-2021. The year with the most article productions was 2021, with a total of 127 articles produced. Meanwhile, the fewest article production occurred in 2012 (n = 70) and 2014 (n = 62).
- Answer on research question 2: the majority of TPACK publications on science education were written by corresponding authors from the United States, followed by Turkey and Germany. This result is not accordance if linked to individual author analysis that Nilsson P, from Sweden, is detected as most productive author in the field. Park S, author from USA, takes place in second position. Furthermore, the

most cited article about TPACK is written by Voogt J (2012), from Netherlands. Yet, article with the highest local citations is still written by Park S, corresponding author from the United States. In terms of multiple country publications, China gained the highest percentage, followed by United Kingdom and Turkey. Instead, United Stated gained the small percentage of multiple country publications.

We believe that the answers from research questions 1–2 deliver a hint for forthcoming development of TPACK framework among science education researchers from various countries. Because many authors and countries have contributed to the development of TPACK framework in science education, these findings may stimulate the researcher community to consider scientific publication on the subject in a prestigious journal as a future potential task. A few, in particular, have begun a multi-country collaboration in publishing scientific results on TPACK. This recommendation is accordance with global agenda among education researchers in twenty-first century on studying how teachers integrate technology into teaching (Zhang, 2014; Srisawasdi, 2014; Bilici, Guzey & Yamak, 2016; Kadıoğlu-Akbulut et al., 2020; Tanak, 2020). It is a continuous challenge to prepare teachers for effective technology integration (Baran & Uygun, 2016). Besides, a closer look at the preparation of science teachers is crucial to help students reach various learning goals (Hermita et al., 2021).

- Answer on research question 3: The TPACK researcher community has not yet established a stable international collaboration. Rather, some researchers have collaborated on a number of smaller, mostly national co-authorships.

We believe that the results of research question 3 (see Figures 7 and Table 5) are important data for the research community since they show the necessity for stronger (multinational) collaboration to improve the field. In fact, Mendeley has a crowd sourced bibliography of TPACK-related papers. But, it has not prompted researchers in the field Many previous studies have demonstrated the development of research collaboration, so the efforts will not be futile (Glänzel, 2001). Several studies have found that scientists in developing countries are not isolated from the global research community (Shrum & Campion, 2000), and the number of international co-authors has increased in both developed and developing countries in recent decades (Glänzel & Schubert, 2010; Gaillard, 2010). In addition, International collaboration is essential in developing countries' efforts to increase scientific capacity (Elbe & Buckland-Merrett, 2017; Nagendra et al., 2018; Sachs et al., 2019).

One way to respond to the results is to establish a research community focused on TPACK framework in science education as a forum for international researchers to collaborate on future projects. As the most productive country in TPACK research, researchers from the United States can spearhead this effort. This practice has been observed in other fields, such as Quantum Physics Education as part of the European Quantum Flagship (Bitzenbauer, 2021).

- Answer on research question 4: Many related keywords were used in science education research within TPACK framework. The cluster formed cannot be determined using co-word analysis. It is led by the fact that TPACK framework can be extensively implemented and developed in favor integrating technology into learning process. It is in accordance to the nature of TPACK which comprise the

technology, pedagogy, and content domains. These large interaction between its domains brings many keywords up to the literature.

In introduction section, we have described numerous efforts among TPACK researchers in studying how teachers integrate technology into classroom learning since the rapid advancement of technology in twenty-first century. The study gave huge interest in pre- and in- service preparation to TPACK instrument validation to measure teachers' readiness in integrating technology into their classroom. It is consistent with the co-words analysis result, which includes many clusters with a variety of research foci.

The occurrence of new keywords currently included in TPACK research in science education is revealed by co-words analysis, such as higher education, STEM, and scientific inquiry. According to the literature, there has been a steady increase in the use of TPACK, particularly in teacher education among pre service teachers (Voogt et al., 2013; Yeh et al., 2017). Pre service teachers in higher education are crucial parts in understanding and implementing TPACK framework in the learning process (Bilici, Guzey & Yamak, 2016; Tanak, 2020). In addition, Graham (2011) advocates for the use of research findings to "constructively strengthen" the theoretical work of TPACK research, which he sees as clearly lacking. It impacts higher education involves most and emerges frequently in recent TPACK research.

The role of technology, as the regular part of both STEM and TPACK, resulting these terms frequently examined in the recent studies (e.g., Chai, Rahmawati, & Jong, 2020; Chaipidech et al., 2021; Schmid, Brianza, & Petko, 2021). STEM interdisciplinary teaching and technology integration for subject matter learning are two important abilities that pre service teachers must begin to improve (English, 2017; Chai et al., 2019) and likely to improve students' knowledge and skills, which are important for their future careers (O'Sullivan & Dallas, 2010). The role of technology in term of both STEM and TPACK may be dissimilar in different context (Chai, Rahmawati, & Jong, 2020). It is less probable to be a generated result of STEM in the school context, but it could be as a pedagogical instrument to facilitate learning process (Chai et al., 2019). As a result, teachers must perform their existing TPACK, when designing lessons for subject matter learning (Koh, Chai, & Lee, 2015). However, students will face authentic engineering problems when STEM education is based on engineering design challenges, necessitating the use of technology as a productive, collaborative, and intellectual tool to support them gather, synthesize, design, and build the necessary understanding (Baker & Galanti, 2017).

Further co-word analysis revealed that keywords related to subject matter such as biology, nature of science, mathematics, computer science, and engineering education are hardly examined in recent years. Meanwhile, investigation to teachers' TPACK in specific content is crucial. In term of measurement, particularly, Archambault and Barnett (2010) stated that the TPACK surveys should be improved by adding content-specific statements and updating technology-related items. In addition, The TPACK construct definitions should be more concrete, and the survey items should be more precisely written (Shinas et al., 2013). Thus, we call for future studies regarding TPACK in science education to give attention on examining teachers' needs and TPACK knowledge in specific content.

In conclusion, the findings of this study may contribute to future developments in science education research

within the TPACK framework, as well as inspire researchers in terms of research foci and multinational collaboration. This extensive TPACK literature inspired this work, with the goal of providing an overview that describes the current state of the scientific literature on this subject and how it shifted to its emerging state.

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