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TPACK Framework Based Research in Mathematical Education: A Systematic Literature Review

Noraidah Othman & Siti Mistima Maat

Faculty of Education, Universiti Kebangsaan Malaysia

Email: aida1202@gmail.com, sitimistima@ukm.edu.my

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Abstract

This systematic literature review aims to identify the themes of the study on the Technology Pedagogical Content Knowledge (TPACK) framework in mathematics education and the research methods used in the studies. The search for articles published from year 2015 to 2020 was conducted through the Google Scholar electronic database. A total of 30 articles were selected. The results show that researchers are more focused on studying the level and effectiveness of technology integration in mathematical learning. Over 50% of the research has been done on teachers compared to students and lecturers in the field of mathematics. The findings also show that technology integration in teaching fraction and algebra is the most frequently studied. Qualitative research method is the dominant research methodology used to study the research objectives regarding the TPACK framework, compared to the quantitative method and the mixed method. Limitations and suggestions for further studies are also discussed.

Keyword: TPACK, Mathematics Education, In-service, Technology.

Introduction

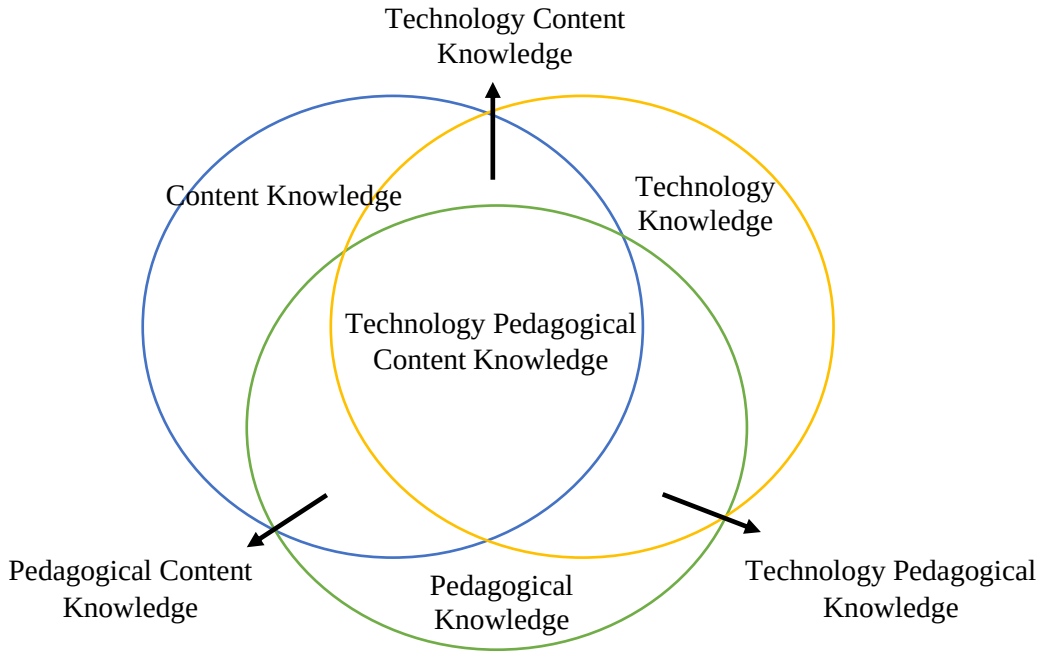
Technological advancements contribute to the transformation of education. In this light, the integration of technology in teaching is considered as a responsive and innovative pedagogical tool in 21st-century learning (Naidoo, 2014). Ansyari (2015) argued that the use of technology has increased rapidly in the educational environment while Holmgren (2015) reported that the use of technology-based tools has led to a positive growth in teaching. This is due to the inclusion of year-round students from different family backgrounds who each have different intelligence and abilities. Thus, there is a need to change the landscape of traditional education if educators want to prepare students to become successful global citizens (Judd, 2015). Educators should be wise in selecting and using technology-based teaching aids that have the potential to enhance students' interest and achievement in the subject.

The National Council of Teachers of Mathematics (NCTM, 2008) recognizes that Information and Communication Technology (ICT) is an important tool for communicating mathematical concepts in the 21st century (Mwambene & Luneta, 2015). Ittigson and Zewe

(2003) further stated that technology is important in teaching and learning mathematical cones. ICT improves the way mathematics is taught and enhances students' understanding of basic concepts. Numerous studies have examined the benefits of using ICT in mathematics. Becta (2003) summarized the main benefits of technology integration as it encourages collaboration among students and promotes communication for knowledge sharing. Subsequently, ICT is considered as a teaching tool and it supports constructivist pedagogy by allowing students to explore and build their own understanding of concepts.

Technological Pedagogical and Content Knowledge (TPACK) was introduced more than a decade ago. Pierson (2001) is one of the early works on this framework, and followed by many others proposinga similar concept of technology integration (Angeli & Valanides, 2005; Koehler & Mishra, 2005). The term TPACK first came to prominence in 2006 following the seminal work of Mishra and Koehler (2005) detailing the model's construction and guidelines. The TPACK framework was originally called "TPCK" and in 2008, it was changed to TPACK, which is easier to pronounce (Thompson, 2008).

The TPACK framework is built on the concept of Pedagogical Content Knowledge by Shulman (1986). Subsequently, technology knowledge components are integrated into the PCK model. The TPACK framework is depicted in the Venn diagram as shown below. It consists of three main overlapping elements representing pedagogical knowledge (PK), content knowledge (CK), and technology knowledge (TK). The combination of these three types of knowledge has created four additional components, namely pedagogy content knowledge (PCK), technology pedagogical knowledge (TPK), technology content knowledge (TCK), and technology pedagogical content knowledge (TPACK). Each knowledge represented in the TPACK framework is described as follows:



Since the emergence of Technology Pedagogical Content Knowledge (TPACK) frameworks (Mishra & Koehler, 2006), more than 500 TPACK-based studies, specifically on the integration of knowledge and technology have been implemented and published. The majority of these studies have focused on TPACK's development of future educators (Setiawan, Phillip, & Isnaeni, 2019). On the other hand, studies on the use of technology by academics in higher education are still lacking (Flavin, 2012). Many international studies have also focused on the development of TPACK for in-service educators (Stoilescu, 2011). However, most of these

studies did not focus on the development of TPACK among in-service mathematics academicians (Eng, & Keong, 2019).

In Malaysia, the Ministry of Education (MOE) has taken the initiative to produce quality educators by utilizing technology to improve the quality of their teaching practices, as explained in the 7th edition of the Malaysian Education Development Plan (PPPM). However, there are still gaps in the educational patterns, especially in mathematics, that need to be studied (Eng, & Keong, 2019). Thus, this systematic literature review aims to answer the following two research questions:

1. What are the key features of TPACK's framework of research in mathematics education?
2. What research methods have been used to conduct studies on the TPACK framework in mathematics education?

Methodology

Article search was conducted to find journal articles related to the TPACK framework. The researcher has set several criteria before the search was performed. First, the year of publication of the article, where the articles selected for this study must be published in the last five years (between 2015 and 2020). The second criterion is the database used to search the article and in this case, the Google Scholar database. The third criterion is the keywords or key terms used to find electronic articles in the database. The keywords used are TPACK or TPCK, and mathematics. The use of Boolean operations "AND" and "OR" were used and these keywords should be mentioned in the abstract, keywords, or title of the study. PCK (Pedagogical Content Knowledge) was not included in the article selection. The fourth criterion is that the article must be in English, but not limited to any country of publication. The next criterion is the scope of the study, specifically mathematics education and includes all levels of education, from pre-education to higher education. The sixth criterion is that the participants or respondents of the study must be students or educators who are in the field of teaching mathematics. Studies conducted on prospective educators, pre-service educators, practical educators and others were not included. Seventh criterion is that only empirical studies were selected while meta-analysis studies, literature reviews, concept papers, systematic studies of analysis and thesis / dissertation were not included in the article selection. Finally, after the potential research articles were identified, a further screening process was performed to ensure that all selected articles meet the stated criteria. The Google Scholar database was used to find articles that meet all the criteria. A summary of the search process of the articles is shown in the PRISMA chart below:

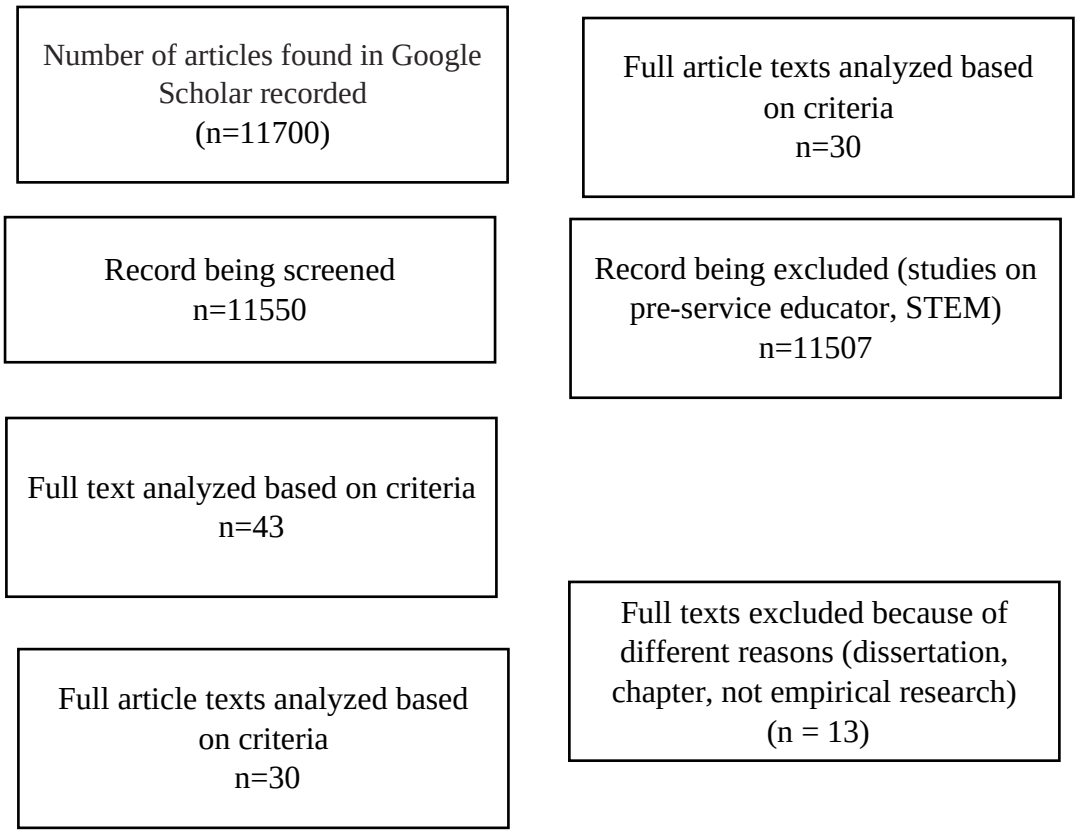


Figure 2: PRISMA Flow Chart

After the in-depth screening process, a total of 30 articles were selected. Each article was summarized in six aspects, (1) the study aspect, (2) the domain of mathematics studied, (3) the country in which the study was conducted, (4) the research design used, (5) the data collection method and (6) educational institutions. Aspects (1) and (2) answer the first research question while the rest answer the second research question. Each article is given a serial number code to facilitate analysis and reference. These data are presented in the form of a Microsoft Excel table. The data were quantitatively analyzed by looking at the frequency of each category. The results of the analysis are then quantitatively compared and contrasted with the data in each category using frequency.

Analysis Results

Research Theme

The analysis begins with a search for similarities and themes differences. Based on the critical analysis carried out on the purpose and questions of research presented in each article, four main research themes were identified, namely (a) identify the relationships among TPACK components, (b) identify the relationship between TPACK components and other variables, (c) identify the extent and impact of the integration of existing and new technologies in mathematics learning, and (d) identify the effectiveness of educators' professional development programs. Table 1 shows the themes identified from previous studies.

The results showed that two studies examined the ability of TPACK among educators of mathematics subjects, which are Harits, et al., (2019) and Mailizar, and Fan (2020). Studies carried out by Loong (2014) and Hansen, A. et al. (2016) explored teachers' development and knowledge through the TPACK framework. In addition, studies compared the level of development of TPACK among educators based on other variables.

Nine articles share the same research theme, which is the relationships between TPACK components and other variables. The other variables included were belief (Lai, T. L., & Lin, H. F., 2018), attitude (Esquincalha, & Abar, 2016; Adulyasas, 2017; Stoilescu, 2015), self-efficacy (Akturk, & Ozturk, 2018; Kang, & Jang, 2016), demographics (Ozudogru, & Ozudogru, 2019), and teaching techniques (Evans, A. et al., 2015).

Mathematics is often considered difficult and tedious by most students. However, the use of technology can encourage collaboration, information sharing, provide quick feedback and increase motivation among students (Gonzalez & Ruiz, 2017). As such, many articles have been published to identify the effectiveness of existing and new technologies in mathematical learning. Among the technologies used are smart devices (tablets) (Tsouccas, & Meletiou-Mavrotheris, 2019; Ingram, 2016; Miller, 2018), gaming applications (Evans, et al., 2015), smart boards (Muir, et al., 2016; Cabus, et al., 2017) and existing applications such as Facebook (GreGory, et al., 2016) and GeoGebra (Khalil, et al., 2017; Kirikçilar, & Yildiz, 2018).

Professional development of educators is now seen as an important factor in enhancing educators' professionalism (Schwarz, & Kaiser, 2019). Studies conducted by Loong and Herbert, (2018) and Havard, B. et al. (2018) identified the relationship between teacher professional knowledge and student achievement while studies conducted by Loong, and Herbert (2018), Ingram (2016), Martin, et al. (2016), Erduran, and Ince, (2018) and Kang and Jang (2016) focused on the effectiveness of professional development programs to enhance teachers' skills and knowledge in integrating technology in the classroom.

Table 1:
Themes Identified From Past Studies

Author	n	Relationship within TPACK component	The relationship between TPACK components and other variables	Technology integration	Professional Development
Lai & Lin (2018), Esquincalha & Abar (2016), Akturk & Ozturk (2018), Ozudogru & Ozudogru (2019), Evans,. et al. (2015). Adulyasas (2017)	6	/	/		
Patahuddin et al. (2016), Muir et al. (2016), Cabus, et al. (2017), Kirikçilar & Yildiz (2018), Miller (2018). Naidoo (2015), GreGory et al. (2016), Khalil (2017).	8			/	
Loong & Herbert (2018), Havard (2018), Hansen (2016), Martin et al. (2016), Erduran & Ince (2018)	5				/
Loong (2014), Hill & Uribe-Florez (2019), Galleto & Pangilinan (2019), Harits (2019), Mailizar & Fan (2020), Wati& Fitriana (2018), Hill & Uribe-Florez (2019).	6	/			
Tsouccas & M eletiou-Mavrotheris (2019).	1		/	/	/
Ingram et al. (2016).	1			/	/
Evans et al. (2015).	1	/		/	
Kang & Jang (2016).	1	/			/
Stoilescu (2015).	1		/		

Mathematics domains being studied

The results show that there are four mathematical domains studied by the previous researchers, namely fractions (Patahuddin et al., 2016; Evanset al., 2015; Hansen et al., 2016), geometry (Kirikçilar & Yildiz 2018; Kang & Jang 2016), algebra (Kirikc; Ilar& Yildiz2018; Evanset al., 2015; Khalilet al., 2017) and linear equations (Wati & Fitriana, 2018). Furthermore, researchers do not specifically specify mathematical domains.

Research Context

Countries where Research is Done

Table 2:

Countries Where Studies Were Conducted

Country	Number of Studies	Article
Taiwan	1	Lai & Lin (2018)
Indonesia	5	Patahuddin (2016), Loong (2014), Haritset al. (2019), Mailizar& Fan (2020), Wati & Fitriana (2018)
Cyprus	1	Tsouccas & Meletiou-Mavrotheris (2019)
Brazil	1	Esquincalha & Abar (2016)
Australia	2	Loong & Herbert, S. (2018), Muir (2016).
Amsterdam	1	Cabus et al. (2017)
Turkey	3	Akturk, & Ozturk, H. S. (2018), Ozudogru, & Ozudogru (2019), Erduran & Ince (2018).
Romania	1	Kirikçilar & Yildiz (2018)
Canada	3	Evans et al. (2015), Miller (2018), Stoilescu (2015).
United States of America	5	Havard, (2018), Hill & Uribe-Florez (2019), Martinet al. (2016), GreGory (2016)
New Zealand	1	Ingram (2016)
Thailand	1	Adulyasas (2017).
Africa	1	Naidoo (2015)
Phillipines	1	Galleto & Pangilinan (2019)
Korea	1	Kang, S., & Jang, M. (2016)
Pakistan	1	Khalil et al. (2017)
Europe	1	Hansen et al. (2016)

Table 2 presents an overview of the research location and it is clear that most of the studies are from Indonesia and the United States with five articles each. Many Asian and European countries have contributed articles using the TPACK framework.

Research Participants and Educational Institution

Table 3:

Research Participants And Educational Institution

Participants	Students	Teacher	Lecturer	N
Pre School		Miller, T. (2018)		
Primary School	Khalil, M. et al. (2017)	Tsouccas, L. F., & Meletiou-Mavrotheris, M. (2019), Loong, E. Y. K., & Herbert, S. (2018), Muir, T., et al. (2016), Hansen, A. et al. (2016), Martin, C. S. et al. (2016), Harits, M., et al. (2019)		7
Secondary School		Lai, T. L., & Lin, H. F. (2018), Patahuddin, S. M. et al. (2016), Esquincalha, A. D. C., & Abar, C. A. (2016), Cabus, S. J. et al. (2017), Akturk, A. O., & Ozturk, H. S. (2018), Kirikçilar, R. G., & Yildiz, A. (2018), Ozudogru, M., & Ozudogru, F. (2019), Evans, M. A. et al. (2015), Havard, B. et al. (2018), Loong, E. Y. K. (2014), Evans, M. A. et al. (2015), Adulyasas, L. (2017), Hill, J. E., & Uribe-Florez, L. (2019), Mailizar, M., & Fan, L. (2020), Wati, S., & Fitriana, L. (2018), Erduran, A., & Ince, B. (2018), Kang, S., & Jang, M. (2016), Stoilescu, D. (2015).		18
Higher Education	Naidoo, J. (2015), Galleto, P. G., & Pangilinan, N. B. (2019)		GreGory, P. L. et al. (2016).	3
N	3	25	1	29

Mathematics has been introduced to students since the beginning of school and the learning continued through higher education. Table 3 shows the participants and educational institutions involved in the study using the TPACK framework. A total of 25 articles were conducted on teachers; of which 18 were conducted on secondary teachers; six were on primary and pre-school teachers. Only one study based on the TPACK framework was tested on lecturers from institutions of higher learning. This is consistent with the observation by Wu, Hu, Gu, & Lim, (2016) that studies on lecturers are limited. They added that although lecturers typically receive more academic training and have higher academic degrees, this does not mean that the subject's expertise gives them the ability to teach and integrate the technology learned in teaching.

Research Design

Table 4:

Research Design And Research Method For Each Article

Article	Research Design				Data Collection Method			
	Quantitative	Qualitative	Mix	Questionnaire	Pre-Test	Observation	Interview	Document Analysis
Lai & Lin (2018)	/			/				
Patahuddin. et al. (2016)		/						
Tsouccas & Meletiou-Mavrotheris			/	/			/	
Esquincalha & Abar (2016)		/				/		
Loong & Herbert (2018)							/	
Muir et al. (2016)						/	/	/
Cabuset al. (2017)		/			/	/		
Akturk & Ozturk (2018)	/			/				
Kirikçilar & Yildiz (2018)			/			/	/	
Ozudogru & Ozudogru (2019)								
Evans et al. (2015)			/		/	/	/	
Havard et al. (2018)	/			/				/
Ingram et al. (2016)		/					/	
Loong (2014)			/	/		/	/	
Hansen (2016)		/				/	/	/
Miller (2018)			/		/	/	/	
Evans et al. (2015).		/			/		/	
Adulyasas (2017)	/			/				
Hill & Uribe-Florez (2019)			/	/			/	
Naidoo (2015)		/		/			/	
Martinet al. (2016)			/		/			/
Galleto & Pangilinan (2019)	/			/				
GreGory et al. (2016)	/			/				
Harits et al. (2019)		/				/	/	
Mailizar & Fan (2020)	/			/				
Wati& Fitriana (2018)			/	/			/	
Erduran & Ince (2018)		/				/	/	/
Kang& Jang (2016)	/			/				
Stoilescu (2015)		/				/	/	/
Khalil et al. (2017)		/			/			
	8	**11**	**8**	**13**	**6**	**11**	**16**	**6**

Research methods refer to how researchers obtain information to achieve the research goal (Rich & Elster, 2019). The study method was categorized into two, namely study design and data collection method. There are three research methods namely quantitative, qualitative and mixed methods. Methods of data collection include questionnaires, pre- and

post-tests, interviews, observations (for example, observations during learning sessions, videos) and document analysis (including lesson plans, student assessment, transcripts and others).

The results showed 11 articles using qualitative methods compared to eight articles for both quantitative and mixed methods. Meanwhile, the interview was most widely used in the study of 16 articles. Many researchers have tested the validity and reliability of the TPACK questionnaire (Schmidt, 2009; Elas, Majid & Suthagar, 2019; Sahin, 2011). Therefore, researchers such as Tsouccas, & Meletiou-Mavrotheris, (2019); Adulyasas (2017); Hill & Uribe (2019); Galleto & Pangilinan (2019); Wati & Fitriana (2018); and Kang& Jang (2016) have adopted the TPACK questionnaire in their study. However, there is also a TPACK questionnaire that has been modified into a TPACK-MT which focuses more on mathematics education, adopted by Patahuddin, et al. (2016) ; Mailizar and Fan (2020) in their study.

Conclusion

This systematic literature review is based on the empirical study of content pedagogical technology (TPACK) knowledge in mathematics education. Previous studies published in the Google Scholar database have been selected in various screening processes. A total of 30 articles were selected and analyzed. Research questions for this systematic literature review have been identified as (1) What are the main features of the study related to the TPACK framework in mathematics education? (2) What research methods have been used to conduct studies on the TPACK framework in mathematics education?

For the first research question, the main theme of the empirical studies on TPACK framework was identified. The findings show that there are four main themes, namely (a) identify the relationships among TPACK components, (b) identify the relationship between TPACK components and other variables, (c) identify the effects of integrating existing and new technologies in mathematical learning and (d) identify the effectiveness of educators' professional development programs. Researchers are more focused on studying the level and effectiveness of technology integration in mathematical learning. Studies have also been conducted to look at the relationship between elements in the TPACK framework with other variables such as demographics, perceptions, self-efficacy, attitudes and beliefs.

Next, the research methodology used to conduct TPACK framework studies in mathematics education has also been identified. There are many studies conducted in Asia and continental Europe based on the TPACK framework. These studies are more often done on mathematics teachers than towards students and lecturers. Researchers are more focused on mathematics teachers in high school. The domain of mathematics is widely studied in education. However, the integration of technologies based on fractional and algebraic topics has also been studied. This is because the use of technology in these topics makes it easier for teachers to increase student interest and achievement (Evans et al., 2015; Patahuddin, 2016). The qualitative research method is dominant over the quantitative method and the mixed method is used to study the research objectives based on the TPACK framework.

Nevertheless, this systematic literature review has some limitations. Some of the criteria set out in this article are based on the researcher's conclusions. Articles selected primarily from Google Scholar may not be subject to peer review or expert review. The articles selected were only articles in English, which may have influenced the findings that most articles were published from Europe.

This systematic literature review analyzes only 30 related articles. Therefore, future studies need to confirm the generalizability of the findings in this study with a broader

domain. These studies in the broader context may indicate greater validity in specific domains such as algebra, linear equations, indexes or logarithms. Some future directions that can be considered are to develop meta-analysis of the related TPACK framework in mathematics education as well as by providing integrative view of TPACK component in various fields. An imperative strategy of TPACK in teaching mathematics is also required in order to develop technology knowledge roadmap for teachers.

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