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The Trend of Technology Pedagogical Content Knowledge (TPACK) Research in 2012-2022: Contribution to Science Learning of 21st Century

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Abstract: The use of TPACK in 21st Century Science learning can facilitate teachers and students to be more active in learning and make it easier for students to have the expected 21st-century competencies. This study aims to identify and analyze TPACK research trends in 21st-century science learning in the form of TPACK documents, classification of journal rankings, classification of authors and their country of origin, and classification of keywords. This research is qualitative research. The data used in this study were obtained from documents indexed by Google Scholar from 2012-2022 using Publish or Perish and dimension.ai. Research procedures using PRISMA guidelines. Methods of data analysis using bibliometric analysis assisted by VOSviewer software. The results of the analysis show that the trend of writing TPACK articles in 21st Century Science learning has increased significantly from 2016 to 2020. Most journals that contain articles about TPACK in 21st Century Science learning are Educational and Information Technologies and Computers & Education. The results of the density mapping analysis show that the themes that are rarely researched are ICT investigation, curriculum, effectiveness, teacher knowledge, foreign language, teacher education, and TPACK instrument.

Keywords: Science learning; TPACK; 21st century

Introduction

21st-century learning is learning that combines literacy skills, knowledge abilities, skills, behaviors, and mastery of technology (Dakhi et al., 2020; Jannah et al., 2020; Silber-Varod et al., 2019). Life and career in the 21st Century require the ability of students and teachers to be productive and accountable, have social and cultural skills, be flexible and adaptive, be initiative and independent, and have leadership and be responsible (Caena & Redecker, 2019; Sumardi et al., 2020; Tohara, 2021). Learners must also master information, media, and technology, namely information literacy, media literacy, technological literacy (Bahtiar & Ibrahim, 2022; Blau et al., 2020; Kaeophanuek et al., 2019; Bahtiar, B, et al., 2022). 21st-century competencies are the main focus for increasing the capacity of human resources in Indonesia (Bahtiar et al., 2022; Liza & Andriyanti, 2020). These competencies become guidelines for forming human beings who have the ability to compete in the world of work (Anthonysamy et al., 2020; Cote & Milliner, 2018; Reinhardt & Thorne, 2019;). 21st-century learning is a way to realize the fulfillment of these competencies to solve problems including in learning science in schools (Gunawan et al., 2020; van Laar et al., 2020; Y. Wang et al., 2018; Wrahatnolo, 2018; Rahayu, Y.S. et al., 2028).

Science learning is an instruction that gives students hands-on experience to strengthen their ability to absorb, retain, and apply the principles they have

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studied (Puspitarini & Hanif, 2019; Rapanta et al., 2020). In essence, scientific methods, procedures, and mindsets serve as the foundation for science (de Moura Jr, 2021; Vapniarchuk et al., 2021). The purpose of learning science is to develop students' capacity to meet their requirements in a variety of contexts, notably in dealing with the challenges of modern life (Butler et al., 2018; Darling-Hammond et al., 2020). So far science learning is still not in accordance with the demands of the 21st century (Bahtiar, 2018; Hanif, 2020; Jdaitawi, 2020). Science learning still uses learning methods that have not maximized students to play an active role in the learning process. In addition, science learning in Indonesia is still seen as learning that only focuses on low-level knowledge.

Differences in education in several countries produce students with different abilities (Hanushek et al., 2019). Based on the results of the PIRLS and TIMSS tests, it is known that Indonesian students are unable to answer questions that require higher-order thinking skills. Indonesian students' PISA scores related to literacy, numeracy, and science in 2018 also show that Indonesian students' abilities are still below average, even decreasing compared to the assessment three years earlier as shown in the following Figure 1.

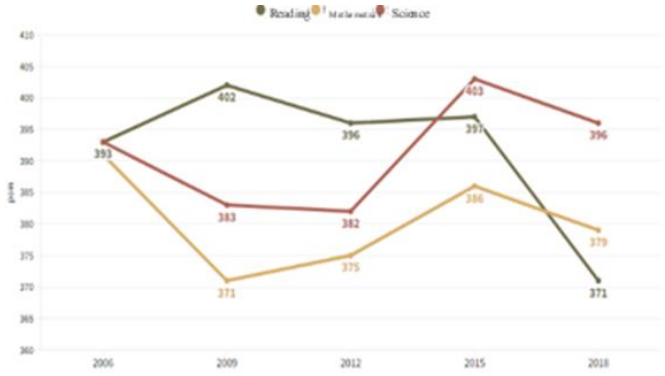

Figure 1. PISA results report 2006-2018

The figure above shows that 2018, Indonesia had a reading score of 371 in 2018, the lowest since 2003. This score also placed Indonesia in the 64th position out of 74 countries (Dovlatova et al., 2022; Surya et al., 2020). Indonesia also recorded a numeration or mathematical calculation score of 379. This figure decreased compared to 2015 which amounted to 386 and was in the 73rd position. Indonesia's science score was 396. The figure also decreased from 2015 which amounted to 403 and was ranked 71st. This condition had an impact on the low quality of human resources in Indonesia. Of the many learning methods, none adhere to the HOTS system. Learning conducted by Indonesian teachers still uses the Lower-Medium Order Thinking type method. This fact is proof that the education system needs to be overhauled as a whole.

Therefore, a shift in learning methods must be made to anticipate the needs of the 21st century. The characteristics of 21st-century learning are information, automation, computing, and communication (Chuntala, 2019). One of the learning approaches that can be used in science learning according to the 21st century is Technology Pedagogical Content Knowledge (TPACK) based learning.

TPACK is knowledge about the integration of technology and pedagogy in the development of content in education (Akyuz, 2018; Tseng et al., 2020; W. Wang et al., 2018). In order to simplify pedagogical practice and comprehend concepts by integrating technology into the learning environment, TPACK is also a framework for comprehending and articulating the sort of knowledge required by a teacher (Baran et al., 2019; Mutiani et al., 2021). TPACK was first introduced by Mishra and Koehler in 2006. The 2006 TPACK framework focuses on technological knowledge, pedagogical knowledge, and content knowledge (Lachner et al., 2021; Tondeur et al., 2020).

Koehler and Mishra formulated TPACK into seven elements (Mishra, 2019). These elements are commonly referred to as the seven knowledge domains, namely Pedagogical Knowledge (PK), Content Knowledge (CK), Technology Knowledge (TK), Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TCK), Technological Pedagogical Content (TPACK) (Taopan et al., 2020). Every teacher must be able to put forward a learning model that is in line with the conditions of their students. TPACK is able to provide new directions for teachers on how to apply technology in learning so that learning activities can run effectively and efficiently. The following presents the TPACK framework in the form of an image.

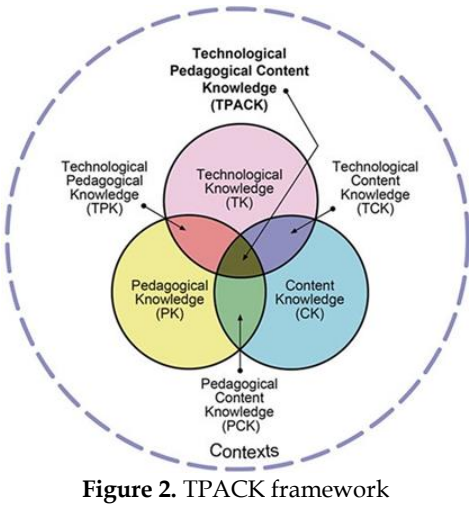

Figure 2. TPACK framework

The figure above shows that the elements of TPACK are interconnected. Technological pedagogical knowledge describes the relationships and interactions between technological tools and specific pedagogical practices, whereas content pedagogical knowledge describes the commonalities between pedagogical practices and specific learning objectives (Dong et al., 2020; Tanak, 2020). Ultimately, technological knowledge describes the intersectional relationship between technology and learning objectives. This triangulation area then becomes TPACK.

Therefore, based on the description above, the researcher is interested in conducting a trend analysis of TPACK research in 21st-century science learning. This research is important for several reasons: 1) with this analysis, science teachers in secondary schools are able to make changes to learning methods used in science learning; 2) the results of this analysis can be used by teachers and researchers in the science field in conducting research related to TPACK in science learning; and 3) the results of this analysis can be used as a reference source for teachers and researchers in the field of TPACK in science learning.

Method

This research is qualitative research. Qualitative research is research that is descriptive in nature and tends to use analysis in which the researcher is the key instrument (Farghaly, 2018). The data used in this study were obtained from documents indexed by Google Scholar using Publish or Perish and dimension.ai. The keywords used in the Google Scholar search are TPACK and science learning. The documents analyzed were 640 Google Scholar-indexed documents between 2012 and 2022. The selection of the Google Scholar database as a place to search for documents is because Google Scholar applies consistent standards in selecting documents to be included in its index, and Google Scholar displays more documents than top databases. others, especially research in the fields of education and social sciences (Hallinger & Chatpinyakoop, 2019; Hallinger & Nguyen, 2020). To filter the data collected through Publish or Perish, researchers use the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines as.

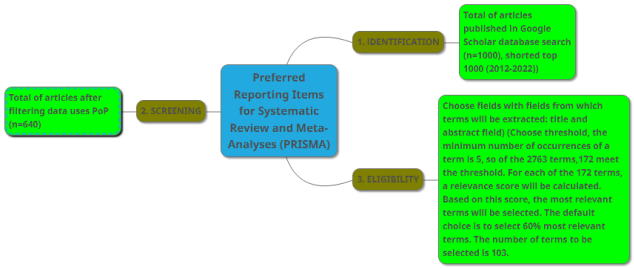

Figure 3. Research procedure based on PRISMA

Result and Discussion

This study aims to analyze the trend of TPACK research in 21st century science learning. TPACK-based learning is very important to be applied in 21st century science learning. Therefore, TPACK has been widely studied by researchers. In the following, TPACK's research trends are presented based on the type of publication.

Table 1. Trend TPACK on Science Learning Research Based on Publication Type

Publication Type	Publications
Article	5,411
Chapter	2,440
Edited Book	637
Proceeding	581
Monograph	220
Preprint	80

Table 1 shows that research on TPACK from 2012 to 2022 is contained in five types of publications, namely in the form of 5,411 articles, 2,440 chapters, 637 edited books, 581 proceedings, 220 monographs, and 80 preprints. Of the five types of publications, it can be seen that articles are the type of publication that contains a lot of TPACK from 2012 to 2022. Research by (Doncheva et al., 2018; Emrouznejad & Yang, 2018) show that the type of publication that is widely used for the publication of scientific work is journals. The number of published document articles about TPACK is scattered in several accredited journals. The following presents the top ten (10) journal sources that have published a lot about TPACK from 2012 to 2022.

Table 2. Top 10 Researchers on Trend TPACK Research in 2012-2022

Name	Organization	Country	Publications	Citations	Citations Mean
Ching Shing Chai	Chinese University of Hong Kong	China	50	1,698	33.96
Punyashloke Mishra	Arizona State University	United States	38	2,819	74.18
Jo Tondeur	Vrije Universiteit Brussel	Belgium	35	2,664	76.11
Joke M Voogt	University of Amsterdam	Netherlands	33	2,158	65.39
Tommy Tanu Wijaya	Guangxi Normal University	China	29	140	4.83
Chin-Chung Tsai	National Taiwan Normal University	Taiwan	28	950	33.93

Name	Organization	Country	Publications	Citations	Citations Mean
Joyce Hwee Ling Koh	University of Otago	New Zealand	27	1,277	47.30
Roy D Pea	Stanford University	United States	25	189	7.56
Danah Anne Henriksen	Arizona State University	United States	24	287	11.96
Maxine Mckinney De Royston	University of Wisconsin Madison	United States	24	178	7.42

Table 3. Top 10 Sources Title Trend TPACK Research in 2012-2022

Name	Publications	Citations	Citations Mean
Educational and Information Tecnologies	225	2,371	10.54
Computers & Education	142	7,968	56.11
TechTrends	129	91	0.71
Advances in Social Science Education and Humanities Research	108	238	2.20
Lecture Notes in Computer Science	93	1,577	16.96
Tech Trends	91	1,679	18.45
British Journal of Educational Technology	84	1,416	16.86
Journal of Digital Learning in Teacher Education	82	205	2.50
Communications in Computer and Information Science	74	144	1.95
Journal of Physics Conference Series	66	215	3.26

Table 3 shows that the researcher who has published the most articles about TPACK in learning is Ching Shing Chai. Ching Shing Chai is a researcher from the Chinese University of Hong Kong, China. Ching Shing Chai wrote articles about TPACK and published them in 50 journals with an average annual citation of 33.96. The next researcher who has written and researched a lot about TPACK is Mintashloke Mishra with 38 publications. The average number of citations per year for an article published by Mintashloke Mishra is 74.18 citations. One of the documents about TPACK that Ching Shing Chai once wrote was entitled "Enhancing and modeling teachers' design beliefs and efficacy of technological pedagogical content knowledge for 21st century quality learning" (Chai et al., 2019). In addition to the top 10 researchers regarding TPACK mentioned in the table above, the following is also presented by other researchers regarding TPACK.

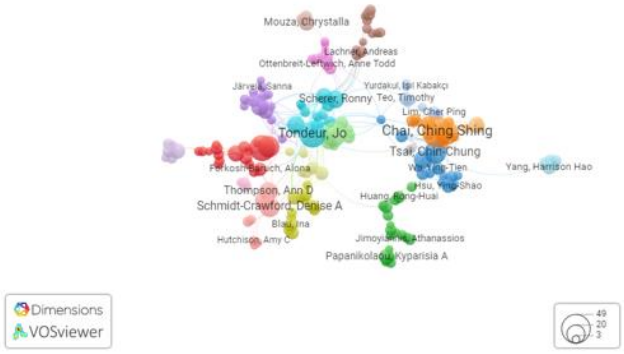

Figure 5. Researchers on TPACK 2021-2022

Figure 5 shows that the relationship between one researcher and another researcher in writing or citing articles about TPACK in learning. In the figure there are 175 researchers with 411 co-authorship links, and a total of 1077 co-authorships. Like researcher Ying-Tien Wu with corresponding authors Ching-Shing Chai and Li-Jen Wang who researched "Exploring secondary school teachers' TPACK for video-based flipped learning: the role of pedagogical beliefs". The results of his research show that pedagogy has a relationship with content knowledge (CK), pedagogical knowledge (PK), pedagogical content knowledge (PCK), technological content knowledge (TCK), and technological pedagogical knowledge (TPK).

Table 4. Keyword on Trend TPACK Research in 2012-2022

Terms	Occurrences	Relevance
ICT Integration	7	1.83
Pandemic Covid-19	7	1.64
Higher Education	9	1.57
PCK	6	1.48
Blended Learning	5	1.48
TPK	6	1.46
TPACK Research	10	1.46
Teacher Knowledge	5	1.44
TPACK Instrument	9	1.30
Physics	9	1.28
Communication Technology	9	1.27
EFL Teacher	10	1.22
Curriculum	9	1.20
TCK	5	1.19
TPACK Approach	7	1.04
Teacher Education	10	0.77
Preservice Science Teacher	8	0.74
Gender	8	0.74
TPACK Competency	9	0.74
Science Teacher	20	0.50

In the articles researched and written by these researchers, there are many terms/key words related to TPACK in learning. The following presents twenty (20)

popular keywords related to TPACK in 21st century learning.

Table 4 shows that the keywords that appear the most are related to science teacher 20 times with a relevance of 0.50. These keywords appear in several journals analyzed. This indicates that in the TPACK topic in learning, researchers associate a lot with science teachers in conducting research. Keywords that are often used by researchers in research on TPACK in science learning include ICT integration, TPACK elements (PCK, TPK, PK, CK, TK, and TCK), teacher education, gender, preservice science teacher, TPACK instrument, physics, and others. (Dewi et al., 2021) also stated that there are 14 keywords that often appear in articles about TPACK including knowledge, teacher, technology, service, educational, and others.

This discussion will present a graphical visual mapping of published articles with the theme TPACK in 21st Century Science learning. The results of this analysis become the interpretation of article publications based on research objects that are often studied and analyzed. Related to bibliometrics, science mapping is a method for visualizing the object of study from a field of science (Chandra, 2018; Chen & Song, 2019). This visualization is carried out by creating a landscape map which can provide visual information on topics of study from science. The results of the bibliometric mapping of the co-word map network for the publication of articles with the theme of TPACK in 21st Century Science learning can be seen in the following figure 6.

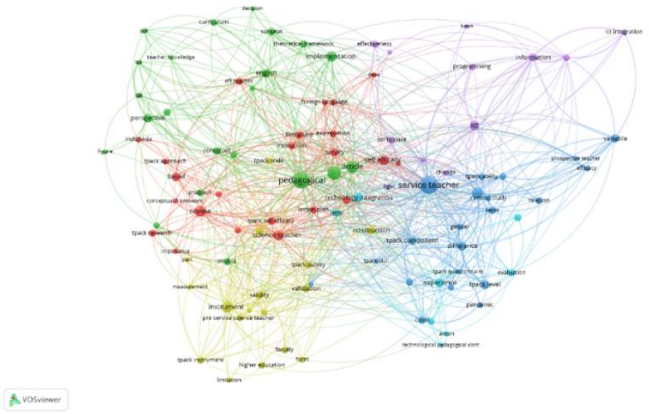

Figure 6. Circles network visualization

Figure 6 shows the results of mapping bibliometric keywords in the TPACK research trend in 21st Century Science learning. In the figure there are 103 keyword items that are often used in TPACK research in 21st Century Science learning from 2012 to 2022. The figure also contains 6 clusters, where the first clusters are colored red consisting of 23 keyword items including: science teacher, TPACK approach, self-efficacy, efficient teacher, and others. The second green cluster consists of 22 keyword items, including: curriculum, pedagogical, teacher knowledge, technological, and others. The third blue cluster consists of 21 keyword items, including pandemic covid-19, preservice teacher, prospective teacher, and others. The fourth cluster in yellow consists of 17 keyword items, including TPACK instruments, TPACK surveys, higher education, and others. The purple fifth cluster consists of 12 keyword items, including blended learning, communication technology, ICT integration, and others. The last cluster which is light blue in color consists of 8 keyword items, including teacher education, technology integration, technological pedagogical, and others. The results of the cicles network visualization analysis show the same thing as the results of the analysis carried out by (Suprapto et al., 2021), where there are six clusters in the article about TPACK in learning.

Keywords that are classified into six clusters are arranged in a color chart that shows the divisions/clusters that are connected to each other. The results of this analysis can be used to determine the trend of keyword research in the past year. This analysis shows several keywords that are often used in TPACK research on 21st Century science learning, the more keywords that appear, the wider the visualization displayed. The following also presents keywords about TPACK in 21st Century Science learning by year.

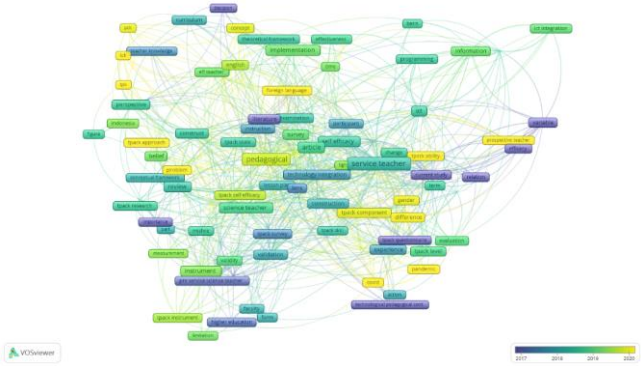

Figure 7. Frames Overlay Visualization

Figure 7 shows the trend of article writing themes in Google Scholar indexed journals by year. Trends in the theme of writing articles related to TPACK in 21st Century Science learning from the oldest to the newest year are marked by themes of purple, blue, tosca, dark green, light green and yellow. This means that the keywords pandemic covid-19, blended learning, problem solving, TPACK component, pedagogical, gender, TPACK ability, prospective teacher in yellow are the latest themes related to TPACK in 21st Century science learning. This can be an up-to-date reference for further research. Research Dewi et al., (2021) also stated that the keywords that were frequently researched from 2019 to 2021 were learning during the COVID-19

pandemic. This can also be seen in the following illustration in Figure 8.

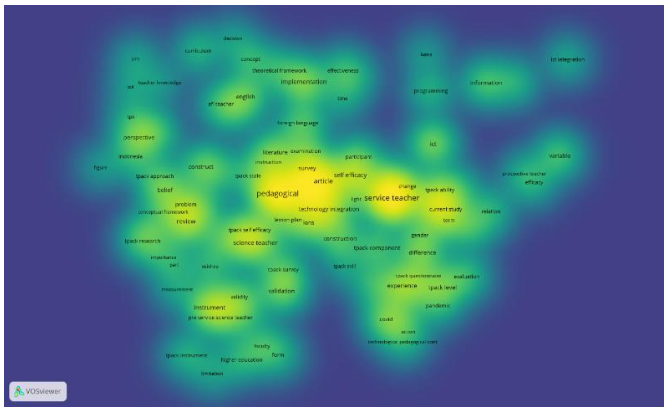

Figure 8. Density visualization

Figure 8 shows the density or density. The density of the research theme is indicated by a bright yellow color. The lighter the color of a theme, the more research has been done. The dimmer the color means that the theme is rarely researched. Dimly colored themes such as ICT investigation, curriculum, effectiveness, teacher knowledge, foreign language, teacher education, TPACK instrument are themes that can be used as references for further research. Kaur et al. (2022) and Liao et al. (2018) states that the yellow color indicates keywords that are being and often used in research.

Conclusion

The trend of writing articles in Scopus indexed and SINTA indexed journals about TPACK in 21st Century science learning in the 2012-2022 period was not too volatile, a significant increase occurred from 2016 to 2020 as the peak. From 2020 to 2022 there will be a decrease in the number of published articles. "Examining the technological pedagogical content knowledge of Singapore pre-service teachers with a large-scale survey" is one of the articles on TPACK in 21st Century learning that has most number of citations. The journals that contain the most articles about TPACK in 21st Century science learning are Educational and Information Technologies and Computers & Education. The results of the density mapping analysis show that the themes that are rarely researched are ICT investigation, curriculum, effectiveness, teacher knowledge, foreign language, teacher education, TPACK instrument.

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