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Meta-Analysis of TPACK Research on Mathematics Education

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ABSTRAK

Tujuan dari penelitian ini adalah untuk menguji pengaruh Pengetahuan Konten Pedagogis Teknologi (TPACK) terhadap kemampuan matematika calon guru dalam mengajar matematika. Desain penelitian adalah tinjauan pustaka, dan subjek yang disertakan adalah penelitian yang tersedia dari situs web jurnal daring. Subjek penelitian dipilih berdasarkan kriteria inklusi penelitian, dan sebagai hasilnya, enam artikel dipilih untuk analisis TPACK terhadap kemampuan matematika. Data dianalisis dalam meta-analisis berdasarkan ukuran efek. Temuan menunjukkan bahwa TPACK memiliki dampak yang signifikan terhadap kemampuan matematika calon guru sebagaimana ditunjukkan dari ukuran efek rata-rata sebesar 1,06. Hasil tersebut juga menunjukkan bahwa efek keseluruhan TPACK terhadap kemampuan matematika adalah 1,06 dan dapat diklasifikasikan sebagai efek yang tinggi.

Kata Kunci: TPACK; Pendidikan Matematika; ukuran efek.

ABSTRACT

The purpose of this study is to examine the effect of Technological Pedagogical Content Knowledge (TPACK) on the pre-service teachers' mathematical ability to teach mathematics. The research design is a literature review, and the subject included is research available from online journal websites. The research subject was selected based on the research inclusion criteria, and as a result, six articles were selected for the analysis of TPACK on mathematical ability. Data were analyzed in a meta-analysis based on the effect size. The findings suggested that TPACK has a significant impact on the pre-service teachers' mathematical ability as shown from the mean effect size of 1.06. The results also indicated that the overall effect of TPACK on mathematical ability is 1.06 and can be classified as a high effect.

Keywords: TPACK; Mathematics Education; effect size.

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1. INTRODUCTION

The 21st-century learning demands an innovative way of thinking and approach to education (Gardner, 2006; Pink, 2005; Handoko & Winarno, 2019). For this reason, learning experts recommend teaching with the support of digital technology to achieve a learning environment thataligns with the significant shifts in pedagogical practices (Pramasdyasari, Aini, & Setyawati , 2024; Fullan & Langworthy, 2014; Fullan, 2013; Friesen & Lock, 2010; Dede, 2009; Scardamalia & Bereiter, 2006). Technological developments can be used in the learning process (Ariani et al., 2017). The existence of innovation for the use of technology in learning can change the learning process (Zainil et al., 2017; Saputro et al., 2024). Perspectives on the role of technology have also expanded both conceptually and operationally (Hooper & Hannafin, 1991; Nuraeni, Nurjanah, & Siregar, 2024). Technology nowcontinues to change how students learn and the expected learning outcomes. One of the reasons schools or colleges continue to adopt technologies in the classroom is to bridge the digital divide related to access to technology (Dijk & Hacker, 2003; Rahayu, Aima, & Juwita, 2023). In addition, assertive, and creative use of technology in mathematics learning helps pre-service teachers develop the skills and knowledge needed to meet the shift in 21st-scentury education (Adelabu et al., 2019; Tamur et al., 2020; Chen et al., 2020; Afriansyah & Turmudi, 2022), in which the teaching process by utilizing the potential of technology is expected to support optimal learning outcomes. Therefore, both lecturers and pre-service teachers are required to have the knowledge and skills to use technology in the classroom, especially in mathematics.

Recently, educational research has focused more on learning in the classroom based on TPACK (Pamuk et al., 2013; Tseng et al., 2022). TPACK learning model is closely related to the use of technology in the teaching and learning process. Technological Pedagogical Content Knowledge (TPACK) is a framework of understanding by combining three main aspects of knowledge, namely content knowledge (material), pedagogy (Arwadi et al., 2024). TPACK focuses on the use of technology and how it can be used to teach content (material) in an appropriate context in order to meet pedagogical needs (Koehler & Mishra, 2009; Toheri, Kismeina, & Persada, 2022).

Students of all disciplines must learn how to design and develop a system to improve their success in today's modern learning environment (Keengwe et al., 2009). One of the most important ways of providing support for the use of technology in learning is by using a framework of thought that integrates a complex problem of content knowledge (material), pedagogy, technology, and various other forms of elements to support learning in the classroom (Koehler et al., 2007; Ferdig, 2006; Mishra & Koehler, 2006; Koehler & Mishra, 2005; Niess, 2005).

Technology Pedagogical Content Knowledge (TPACK) is a perfect combination of three knowledge domains (content, pedagogy, and technology) (Busnawir et al., 2023). TPACK aims to develop basic knowledge. TPACK is a situation where pre-service subject matter teachers understand how technology can increase their students' learning opportunities and experiences (Nuraeni & Juandi, 2023). Having TPACK ability also means that pre-service teachers know how to use the appropriate pedagogy to improve the content of a lesson. In mathematics education, pre-service teachers with a TPACK perspective understand the pedagogy. They have a correct understanding of the use of technology. Pre-service teachers with the right TPACK mindset will be able to engage and motivate themselves in exploring the content of mathematics learning to a greater extent. The TPACK design shows that content knowledge (material) that integrates with technology and pedagogical skills is a prerequisite for creating an effective and innovative classroom learning experience (Abbitt, 2011; Restiana & Pujiastuti, 2019).

TPACK ability is considered very important for pre-service teachers since it allows them to create a personalized design of learning materials (Demirtaş & Mumcu, 2021; Thohir, Jumadi, & Warsono, 2022), especially in mathematics. Pre-service teachers with TPACK ability can integrate technology into their teaching process and apply appropriate learning strategies according to their personalities. The use of technology also helps them to understand the subject matter, i.e., to comprehend abstract mathematical concepts. Thus, pre-service teachers are expected to be able to design a lesson on the abstract mathematical concept in a more concrete, contextual, or realistic way based on the students' level of mathematical abilities. Effective teachers are also expected to be able to take advantage of technology to improve students' understanding, stimulate interest in learning, and enhance students' mathematical skills.

2. METHOD

a. Research Design

The research design of this study is a meta-analysis approach. The meta-analysis approach is research carried out by combining primary research findings and then reviewing those findings to provide a more comprehensive description of a phenomenon. This research used quantitative measures for the meta-analysis approach due to the numerical calculations performed to create and extract information from several data. This research was conducted using the following steps, including: (1) the inclusion criteria, (2) the description of the process of finding empirical data and coding variables, and (3) the description of statistical techniques used in the research (Pigott & Polanin, 2020).

The researchers analyzed the effect of Technological Pedagogical Content Knowledge (TPACK) on mathematics learning from previous studies listed in journals. The researchers examined the findings of journals related to the impact of TPACK on various school levels. Then, the researchers examined theories and research findings that support the solution to the research problems, specifically on the effect of TPACK on mathematics learning at various school levels. Theoretical studies are then carried out to strengthen the reasons for drawing conclusions in solving the research problems.

b. Inclusion Criteria

The studies included in this research were selected from journal articles that used experimental or quasi-experimental methods to compare the students' ability who studied mathematics using the Technological Pedagogical Content Knowledge (TPACK) model and students who studied using other learning models. The studies included are also limited to those conducted in Indonesia in the last ten years (2010 - 2020). The statistical data utilized to analyze the data are the average score, standard deviation, and the number of samples. In addition, the information needed to investigate the formulation of the research problem is the year of study, class of study, sample size, duration of learning with technology, and level of education.

c. Data Collection

Empirical data in this study consist of the findings of previous studies that have been published on the website. Data were identified from electronic databases that include SINTA, ERIC, SPRINGER, Google Scholar, and URLs of national journals. The keywords used are "TPACK, Technological Pedagogical Content Knowledge (TPACK)".

d. Coding Process and Reliability Test

The main requirement to facilitate data analysis and data collection in meta-analysis research is by using a coding system. The instrument in the meta-analysis study was classified into a coding category (Juandi & Tamur, 2021). Wilson revealed that common problems often occur in a coding rule must be taken into account. Two sections address this, namely: a section that provides codes for information related to the studies' empirical findings (effect size), and a section that provides codes related to information on the studies' inclusion criteria. The use of effect size (ES) is closely related to the meta-analysis approach because the interpretation of the effect of the dependent variable on the independent variable and its value can only be compared and acquired through ES value (Wilson et al., 2001).

The identification of the coding and review processes that match the inclusion criteria were conducted transparently by verifying whether each study meets the inclusion criteria and is feasible. Then, the information based on the findings of the combined research was recorded. A combination of codes is used to conclude the amount of research data and coding information related to the effect size of TPACK. The formulation of the research problem was conducted using the effect size. In addition to finding the formulation of the problem, the meta-analysis research hypothesis can be proven from the results of the calculation of the effect size.

The effect size shows the effect of a treatment given during the study. Effect size can also be interpreted as a stage to measure the effectiveness of a learning model that is tested or applied to students (Suparman et al., 2021). The formula used to calculate the effect size value is the Cohen's d formula. The results of the calculations are then concluded to belong to which Cohen's d classification, i.e., whether it is included in the low, moderate, or high category.

$$d = \frac{\bar{x}_1 - \bar{x}_1}{S_{gab}} \quad (1)$$

with,

$$S_{gab} = \sqrt{\frac{(n_1-1)S_1{}^2-(n_2-1)S_2{}^2}{n_1+n_2-2}} \quad (2)$$

Description:

$\bar{x}_1$ = experimental group mean

$\bar{x}_1$ = mean of control group

n_1 = number of experimental samples

n_2 = number of control samples

S12 = experimental group variance

S22= control group variance

e. Statistical Analysis

The interpretation of the results of the calculation of effect size using the classification (Thalheimer & Cook, 2002) is as follows:

Table 1. Effect Size Category

Effect Size (ES)	Category
-0,15 ≤ 0,15	No Effect
0,15 < ES ≤ 0,40	Low
0,40 < ES ≤ 0,75	Moderate
0,75 < ES ≤ 1,10	High
1,10 < ES ≤ 1,45	Very High
1,45 > ES	Excellent

Following Thalhelmer's suggestion (Wilson et al., 2001), the researchers calculated each value of the effect size of this meta-analysis study and the combined effect size. The calculations of the moderator variables as well as the publications' bias were resolved using Cohen's d formula. The use of the Cohen's d formula was due to the research limitation in processing effect size using applications. Moreover, the Cohen's d formula could be processed using Microsoft Excel.

3. RESULT AND DISCUSSION

a. Research Findings

Technological Pedagogical and Content Knowledge (TPACK) on pre-service mathematics teachers analyzed 6 articles. The selection of articles is based on the research characteristics, namely research articles that have been published nationally and internationally during the

2010-2020 period. The research data obtained are in the form of the final calculation of the effect size of the TPACK value. The effect size results obtained are as presented in Table 2 below:

Table 2. Effect Size and Variance of Each Research Result

Code	Authors	Year	Pretest Mean	Posttest Mean	Combined Variance	Effect Size	Source
TPACK 1	Bekir & Sabri	2018	143,28	175,55	13,25	2,44	(Yildirim & Sidekli, 2018)
TPACK 2	Noha, Ali & Fatimah	2017	3,79	3,51	1,87	-0,15	(Alrwaished et al., 2017)
TPACK 3	Abbit	2011	3,26	3,92	1,98	0,33	(Abbitt, 2011)
TPACK 4	Okan & Aysen	2018	276,97	295,5	17,19	1,08	(Durusoy & Kamarete, 2018)
TPACK 5	Chew & Lim	2013	2,65	3,79	1,95	0,59	(Meng & Sam, 2013)
TPACK 6	Recai	2016	92	115	10,71	2,07	(Akkaya, 2016)

Based on Table 2, the overall effect size ranges from -0.15 to 2.44. According to category (Thalheimer & Cook, 2002), five effect sizes are categorized as very good; two effect sizes are classified as excellent; one effect size is classified as high effect; one effect size is classified as moderate, and one effect size is classified as low. Only one study had no effect (negligence effect). The findings of the effect size analysis on TPACK show that the overall average effect size is 1.06 and is in the high effect category.

b. Discussion

The purpose of this study was to determine the effect of TPACK on the mathematical ability of pre-service mathematics teachers. The effect of TPACK on mathematical ability is obtained based on the calculation of the effect size. The calculation of effect size helps the researchers to map and analyze the effects of TPACK. The six articles focused on the effect of TPACK on the mathematical ability of pre-service teachers. The researchers calculated the effect size using Cohen's d formula with the help of Microsoft Excel. The effect size values are categorized into no effect, low effect, moderate effect, high effect, very high effect, and excellent effect (Thalheimer & Cook, 2002).

The average effect size of the analysis of the six articles on TPACK is 1.06. The result of the effect size shows that the implementation of TPACK can indeed improve the mathematical ability of pre-service teachers. The findings also indicate that TPACK has a high impact on the mathematical abilities of pre-service teachers based on the 1.06 size difference between the posttest and the pre-test results. The effect size results show that after treatment was given, TPACK has a high effect on mathematical ability compared to before treatment was given. The pre-test aims to measure the increase in mathematical ability after the TPACK treatment is given. The effect size results also indicate that the application of TPACK is effective in improving mathematical ability. Based on Cohen's d classification, the effect size values are categorized as high, and that TPACK is an effective alternative to improve the mathematical abilities of pre-service teachers. Thus, TPACK is highly significant in improving the pre-service teachers' mathematical abilities.

This finding is in line with research (Alrwaished et al., 2017; Akkaya, 2016), which revealed that there is a significant positive change between the pre-test and the posttest after the TPACK model was used in mathematics learning and that TPACK improves mathematical skills. Pre-service teachers play an important role in the use of technology in teaching mathematics. The experience or competencies of teachers highly influences their perception of the use of technology in teaching (Demir & Bozkurt, 2011). In addition, teachers are also expected to use relevant information and communication technology effectively. Previous researchhas shown that only a few mathematics teachers and pre-service teachers use technology in the classroom despite having positive perceptions of technology (Bozkurt, 2011; Demiraslan & Usluel, 2008). This study was carried out by presenting the significant differences in teacher candidates' perceptions of the use of technology in teaching mathematics before and after the integration of technology. The difference in the effect sizesindicates the high and positive impact of the implementation of TPACK and that the pre-service teachers' knowledge significantly and positively improved, as shown in the posttest.

4. CONCLUSION

Based on the research findings and discussion, it is concluded that TPACK has a high impact on the pre-service teachers' mathematical ability. The combined average effect size is 1.06, which indicates that TPACK has a significant effect on the mathematical abilities of pre-service mathematics teachers. However, these findings are based solely on studies that meet the inclusion criteria, and many other comparative studies have not been analyzed due to the lack of statistical information needed and have not been identified for this study.

It is recommended that further researchers conduct analysison primary research and combine the results of national and international journal articles to provide more comprehensive research findings.

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