



## The Correlation Between Digital Technology Mastery and Pedagogical Skills of Teachers with Mathematics Learning Outcomes: A Meta-Analysis

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### ABSTRACT

The integration of digital technology in mathematics instruction has become increasingly essential to enhance students' cognitive engagement and academic outcomes. The purpose of this meta-analysis is to investigate the correlation between digital technology mastery and pedagogical skills of teachers with mathematics learning outcomes published between 2020 and 2024. This quantitative research with a correlation meta-analysis approach utilized a sample of 59 articles published in journals indexed at least in Google Scholar and having a DOI on CrossRef, obtained from journal databases such as Scopus, ERIC, Direct, and Dimensions. Data collection in this research employed the Publish or Perish software and was analyzed using JASP 0.17.3.0 software, assisted by data transformation with Microsoft Excel, aiming to estimate aggregates, draw Forrest plots, and address publication bias. The results of this research indicate that digital technology mastery and pedagogical skills of teachers have a significant influence on students' mathematics learning outcomes, with results free from publication bias and significant variability between studies as evidenced by the correlation value ( $r$ ) = 0.757. The funnel plot of the 59 studies had varying sample sizes with asymmetric distributions and studies free from potential publication bias strengthened by the plot's display. The research recommends the need to re-evaluate various instruments assessing digital technology mastery and pedagogical skills of teachers to maximize unique variance among the existing variables, and although this study has been generalized, mastery of digital technology and pedagogical skills of teachers can enhance mathematics learning outcomes.

**Kata Kunci:** Digital Technology; Pedagogical; Teacher; Mathematics Learning

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### INTRODUCTION

The digital era in education has undergone significant transformation with the advancement of information and communication technology permeating various aspects such as education. This transformation not only changes how we access information but also how we learn and teach. The success of technology in the classroom heavily relies on its actual usage (Yildiz & Arpaci, 2024). In this regard, mathematics, known as the foundation of many disciplines, is inevitably influenced by technology. For instance, research by Ersen & Alp (2024) illustrates that teaching mathematics with Augmented Reality applications has a positive impact on academic achievement and enhances three-dimensional thinking skills (Aldalah et al., 2019; Medina Herrera et al., 2019). These findings depict that the use of technology in mathematics education provides opportunities to create more interactive, critical, and real-life problem-based learning experiences (Artikbayeva et al., 2023; Cui et al., 2023; Kilag et al., 2023; Yohannes & Chen, 2023).

Mathematics education in schools is not something new at all levels of formal education, ranging from early childhood education to secondary education. Software in mathematics learning such as GeoGebra and e-learning applications has been proven by researchers in various countries. For example, Kaya & Kutluca (2024) illustrated that joining GeoGebra into science instruction essentially progresses understudy execution and yields superior comes about compared to routine strategies (Agyei et al., 2023; Marks et al., 2021; Vennila et al., 2024), even being highly valuable in collaborative efforts to enhance mathematics learning (Lindenbauer et al., 2024). These research findings indicate significant and proven opportunities to enhance the understanding of

mathematical concepts by maximizing digital technology appropriate to the content material and teaching methods used (Bagacina et al., 2024; Bereczki & Kárpáti, 2021; Haleem et al., 2022; Helsa et al., 2023).

However, successful technology integration requires adequate tools, skills, knowledge, and strong motivation from mathematics teachers. Nevertheless, the connection between digital technology skills, teachers' pedagogical capabilities, and students' mathematics learning outcomes is not yet fully understood, and there is still no empirical evidence on the effectiveness of utilizing digital technology in mathematics education both inside and outside the classroom. Especially in the difficulty of effectively integrating digital technology into the curriculum and practices of mathematics education. Research by Salami & Spangenberg (2024) found that the most significant barrier in teaching and learning mathematics is integrating technology with the existing curriculum (Buabeng-Andoh, 2012; Toprakci, 2006; Viberg et al., 2023; Zenda & Dlamini, 2023).

Its impact ultimately depends on the teacher's ability to formulate content knowledge, pedagogy, and technology effectively. In this regard, the concept of Technological Pedagogical Content Knowledge (TPACK) becomes crucial. This study seeks to answer the following questions: (1) How does the use of technology correlate with mathematics learning outcomes? (2) What role does teachers' TPACK play in mediating this relationship? (Boris et al., 2013; Gromik et al., 2023; Jamaan et al., 2024; Li et al., 2024; Palmares & Batisla-Ong, 2023; Thongkum & Buaraphan, 2024), where these three aspects become domains of knowledge that teachers must habitually and thoroughly master to implement technology effectively in teaching. Prospective teachers with higher TPACK levels tend to be more effective in integrating GeoGebra into teaching and learning practices (Bueno et al., 2021; Dockendorff & Solar, 2018; Hill & Uribe-Florez, 2020; Kartal & Çınar, 2024; Yildiz & Arpaci, 2024).

TPACK mastery impacts teachers' ability to design teaching strategies that not only positively utilize technology but also align with subject content and collaborative teaching methods. This includes critical knowledge of the effects of technology that can be used to visualize complex mathematical concepts, analyze appropriate technological tools according to students' learning types, and integrate technology with diverse teaching methods. Hakim & Firmansyah (2024) explain that pedagogical competence is the ability of teachers to actively organize students in an effective learning process (Marnita et al., 2023). This is important because it forms the basis for teaching mathematics well and, of course, helps students understand often perceived difficult mathematical concepts. The research results of Hakim & Firmansyah (2024) show a correlation between academic abilities (such as prospective mathematics teachers) and pedagogical competence.

Several studies have attempted to examine the relationship between technology use, teacher TPACK, and mathematics learning outcomes. Some studies show that effective technology use in mathematics lessons can increase student motivation (Al-Azmi & Al-Shboul, 2024; Fakher & Alshboul, 2024; Swartz, 2024), classroom engagement (Bagacina et al., 2024; Canonigo, 2024; Holincheck et al., 2024; Skordialos, 2024; Wulan & Sulisworo, 2024), and understanding of difficult mathematical concepts. However, other studies reveal challenges faced by teachers in integrating technology, such as lack of training, resistance to change, and infrastructure limitations.

In an effort to address these varying and sometimes contradictory research findings, critical analysis is needed to provide a clearer picture of the relationship between these variables. Meta-analysis is an ideal method to achieve this goal, as it involves combining results from various independent studies to obtain more general and valid conclusions. The research objective is to identify and evaluate the correlation between technology use, pedagogical knowledge, and mathematics learning outcomes. The results are expected to provide evidence-based recommendations for improving teacher preparation programs and the effective integration of digital tools in mathematics education.

## METHOD

### Research Design

This study employs a quantitative meta-analysis method, as it utilizes statistical techniques to combine quantitative data from two or more similar studies (Mueller et al., 2018). Meta-analysis focusing on correlation is used to examine the relationship between two variables by utilizing previous correlation studies (Heri et al., 2018). Therefore, the data summarized in this research are obtained from research publications that have been

published in journals with the main topic being the correlation between digital technology mastery and pedagogical skills of teachers with mathematics learning outcomes from 2020 to 2023. The meta-analysis procedure in this study refers to the concepts of [Borenstein et al., \(2021\)](#) and Heri et al., (2018), namely: 1) determining inclusion criteria; 2) data collection and variable coding, and 3) data analysis.

### Inclusion Criteria

In this meta-analysis study, research articles in the initial search are strictly identified by the researchers, taking into account the research objectives and are evaluated for comprehensive meta-analysis. Only studies that answer the objectives of the meta-analysis process are to be processed ([Tawfik et al., 2019](#)). However, another aspect to be considered is the hypothesis of the meta-analysis research (as outlined in the introduction), which will greatly assist in determining the inclusion and exclusion criteria to be used from the outset to identify relevant research findings ([Borenstein et al., 2021](#)). Therefore, the inclusion criteria used to filter research publication results include: 1) publication year of articles from 2020 to 2024; 2) research findings from various countries written in English; 3) related to digital technology mastery, pedagogical knowledge of teachers, and mathematics outcomes; 4) having a sample; 5) having correlation coefficient values ( $r$ ); 6) full text and downloadable DOI.

**Tabel 1.** Selected studies based on inclusion criteria

<i>Study</i>	<i>Years</i>	<i>Source</i>	<i>Correlation coefficient (r)</i>	<i>Sample</i>	<i>Country</i>
Nurul Shakhida Abu Bakar et al	2020	Journal	0,825	66	Africa
Landysh Sharafeeva	2022	Journal	0,650	74	Rusia
Kubra	2020	Journal	0,726	815	Türkiye
Lukasz Tanas et al	2020	Journal	0,765	150	Poland
Jose M. Marbán et al	2021	Journal	0,356	166	Spain
B Kartal	2020	Journal	0,753	1639	Türkiye
Habis S. Al-zboon	2021	Journal	0,700	612	Jordan
Feriha H	2022	Journal	0,735	141	Amerika Serikat
Zehra Onur	2020	Journal	0,500	920	Türkiye
Bishnu Khanal et al	2020	Journal	0,650	399	Nepal
Mailizar et al	2020	Journal	0,579	159	Indonesia
Gokcen BAKAN et al	2023	Journal	0,334	163	Türkiye
Tommy Tanu Wijaya et al	2022	Journal	0,473	190	Indonesia
Zhiqiang Yuan et al	2023	Journal	0,893	266	China
Leonard Nungu et al	2023	Journal	0,690	88	Rwanda
Mesut Butun	2021	Journal	0,364	133	Türkiye
Marissa R. Fearnley	2020	Journal	0,890	127	Philippines
Hind Abdulaziz Alfadda	2021	Journal	0,346	75	Saudi Arabia
Raija et al	2021	Journal	0,400	2590	Finland
Hasan Ozgur	2020	Journal	0,231	349	Türkiye
Iris Backfisch et al	2021	Journal	0,282	18	Germany
Hassan	2021	Journal	0,820	118	Saudi Arabia
Magdalena	2021	Journal	0,800	1487	Poland
Saif Alneyadi et al	2023	Journal	0,720	120	Arab Saudi
Omer Tayfur Ozturk	2023	Journal	0,641	198	Türkiye
Adeneye Olarewaju A. Awofala et al	2023	Journal	0,640	1120	Nigeria
Wei Li et al	2021	Journal	0,660	23	China
Daniel Moreno et al	2020	Journal	0,288	50	Spain
Juan Luis Cabanillas-García et al	2023	Journal	0,858	255	United Arab Emirates
Ana Bertha Betín de la Hoz et al	2023	Journal	0,691	777	Colombia
Ozan Deniz Kiyici	2021	Journal	0,538	223	Türkiye
Eddiebal P. Layco	2022	Journal	0,870	500	Philippines

Study	Years	Source	Correlation coefficient ( <i>r</i> )	Sample	Country
Hossein Hossein-Mohand et al	2021	Journal	0,623	61	Madrid
Titik Suryani et al	2021	Journal	0,640	1490	Indonesia
Daniel Thurm	2022	Journal	0,270	198	Germany
Nurulwahida Azid et al	2020	Journal	0,405	60	Malaysia
Johannes et al	2020	Journal	0,390	165	Germany
M. Haviz	2020	Journal	0,740	9	Indonesia
Junita Cristi Makawawa et al	2021	Journal	0,110	117	Indonesia
Peter Kortesi et al	2022	Journal	0,878	47	Hungary
Eddiebal P. Layco	2022	Journal	0,870	500	Philippines
Titik Suryani et al	2021	Journal	0,550	584	Indonesia
Hanna Andayani	2020	Journal	0,556	308	Indonesia
Boran	2022	Journal	0,800	30	Türkiye
Andreja Istenic et al	2023	Journal	0,356	606	Croatia
Wenwei Luo et al	2022	Journal	0,784	1192	China
Cyntha B. Pareja et al	2023	Journal	0,779	90	Indonesia
Hannele Niemi	2021	Journal	0,499	121	Finland
Riitta Maarit Oikarinen et al	2022	Journal	0,661	40	Finland
Esra Yildiz & Ibrahim Arpacı	2024	Journal	0,421	205	Türkiye
Pinar Cavas et al	2024	Journal	0,477	345	Türkiye
Rabia Dincer et al	2024	Journal	0,600	101	Türkiye
Pheneas Nkundabakura et al	2024	Journal	0,432	151	Afrika
Angel Mukuka	2024	Journal	0,624	104	Afrika
Kai Li et al	2024	Journal	0,480	132	China
Ke Xin Tan et al	2024	Journal	0,656	148	Malaysia
Rashmi Nautiyal	2023	Journal	0,958	200	India
Hutkemri Zulnaidi et al	2024	Journal	0,630	615	Indonesia
Chia Wen Tsai et al	2024	Journal	0,169	126	Taiwan

### Data Collection and Coding

The primary data in this meta-analysis consist of research findings on the correlation between technology mastery, pedagogical knowledge of teachers, and mathematics learning outcomes. Data can be obtained from online databases. Keywords used in compiling research studies include “technology mastery, pedagogical knowledge of teachers, and mathematics learning outcomes,” as well as equivalent keywords. Then, for the data coding process, it involves several components, including: 1) researcher and publication year; 2) title; 3) sample size; 4) country; 5) source of research publication; 6) correlation coefficient (*r*); 7) Transformation of correlation values to Fisher's (*Z*); 8) variance ( $V_z$ ), and 9) standard error ( $SE_z$ ). For processes 7 through 9, Excel is used with formulas from Heri et al., (2018) as shown in Table 2. The results of data collection and coding in this meta-analysis can be seen in Table 3. The purpose of these procedures is to assist and facilitate researchers in conducting data analysis.

**Table 2.** Calculation of effect size

Step	Formula
Correlation ( <i>r</i> ) transformed into Fisher's	$z = 0,5 \times \ln \left( \frac{1+r}{1-r} \right)$
Variance	$V_z = \frac{1}{n-3}$
Standard error	$SE_z = \sqrt{V_z}$

**Table 3.** Research sample data statistically

Study	Years	$z$	$V_z$	$SE_z$
Nurul Shakhida Abu Bakar et al	2020	1,172	0,016	0,126
Landysh Sharafeeva	2022	0,775	0,014	0,119
Kubra	2020	0,920	0,001	0,035
Lukasz Tanas et al	2020	1,008	0,007	0,082
Jose M. Marbán et al	2021	0,372	0,006	0,078
B Kartal	2020	0,980	0,001	0,025
Habis S. Al-zboon	2021	0,867	0,002	0,041
Feriha H	2022	0,940	0,007	0,085
Zehra Onur	2020	0,549	0,001	0,033
Bishnu Khanal et al	2020	0,775	0,003	0,050
Mailizar et al	2020	0,661	0,006	0,080
Gokcen BAKAN et al	2023	0,347	0,006	0,079
Tommy Tanu Wijaya et al	2022	0,514	0,005	0,073
Zhiqiang Yuan et al	2023	1,437	0,004	0,062
Leonard Nungu et al	2023	0,848	0,012	0,108
Mesut Butun	2021	0,381	0,008	0,088
Marissa R. Fearnley	2020	1,422	0,008	0,090
Hind Abdulaziz Alfadda	2021	0,361	0,014	0,118
Raija et al	2021	0,424	0	0,020
Hasan Ozgur	2020	0,235	0,003	0,054
Iris Backfisch et al	2021	0,290	0,067	0,258
Hassan	2021	1,157	0,009	0,093
Magdalena	2021	1,099	0,001	0,026
Saif Alneyadi et al	2023	0,908	0,009	0,092
Omer Tayfur Ozturk	2023	0,760	0,005	0,072
Adeneye Olarewaju A. Awofala et al	2023	0,758	0,001	0,03
Wei Li et al	2021	0,793	0,05	0,224
Daniel Moreno et al	2020	0,296	0,021	0,146
Juan Luis Cabanillas-García et al	2023	1,286	0,004	0,063
Ana Bertha Betín de la Hoz et al	2023	0,850	0,001	0,036
Ozan Deniz Kiyici	2021	0,601	0,005	0,067
Eddiebal P. Layco	2022	1,333	0,002	0,045
Hossein Hossein-Mohand et al	2021	0,730	0,017	0,131
Titik Suryani et al	2021	0,758	0,001	0,026
Daniel Thurm	2022	0,277	0,005	0,072
Nurulwahida Azid et al	2020	0,430	0,018	0,132
Johannes et al	2020	0,412	0,006	0,079
M. Haviz	2020	0,950	0,167	0,408
Junita Cristi Makawawa et al	2021	0,110	0,009	0,094
Peter Kortesi et al	2022	1,367	0,023	0,151
Eddiebal P. Layco	2022	1,333	0,002	0,045
Titik Suryani et al	2021	0,618	0,002	0,041
Hanna Andayani	2020	0,627	0,003	0,057
Boran	2022	1,099	0,037	0,192
Andreja Istenic et al	2023	0,372	0,002	0,041
Wenwei Luo et al	2022	1,056	0,001	0,029
Cyntha B. Pareja et al	2023	1,043	0,011	0,107
Hannele Niemi	2021	0,548	0,008	0,092
Riitta Maarit Oikarinen et al	2022	0,795	0,027	0,164

Esra Yildiz & Ibrahim Arpaci	2024	0,449	0,005	0,070
Pinar Cavas et al	2024	0,519	0,003	0,054
Rabia Dincer et al	2024	0,693	0,010	0,101
Pheneas Nkundabakura et al	2024	0,462	0,007	0,082
Angel Mukuka	2024	0,732	0,010	0,100
Kai Li et al	2024	0,523	0,008	0,088
Ke Xin Tan et al	2024	0,786	0,007	0,083
Rashmi Nautiyal	2023	1,921	0,005	0,071
Hutkemri Zulnaidi et al	2024	0,741	0,002	0,040
Chia Wen Tsai et al	2024	0,171	0,008	0,090

### Data Analysis

This study is a correlation meta-analysis. Data analysis is conducted with the assistance of JASP 0.17.3.0 Software and Microsoft Office Excel. The correlation meta-analysis chart used in the data analysis of this research consists of several steps, including: 1) transforming each  $r$  value into an effect size; 2) testing for heterogeneity; 3) calculating summary effects; 4) moderator analysis; and 5) evaluating publication bias. Additionally, data visualization is aided through Forest and Funnel Plots.

To interpret the effect size of correlation studies in this research, the scale suggested by Cohen, (1988) is utilized, see table 4. Subsequently, heterogeneity testing in this study is performed using the  $Q$  parameter approach and  $p$ -value. If the  $p$  - value < 0.05, the appropriate estimation model for calculating summary effects is the random-effects model. If the  $p$  - value > 0.05, the fixed-effects model estimation is used. Studies containing the necessary statistics in meta-analysis require publication bias testing (Heri et al., 2018). This research is said to be robust against bias if the spread of effect sizes shows a symmetric distribution around the vertical line (Borenstein et al., 2021). If the effect size is not fully symmetrically distributed, Rosenthal's File-Safe  $N$  (FSN) approach is used to check for publication bias. If the File-Safe  $N$  value > ( $5K + 10$ ), where  $K$  is the number of studies included in the meta-analysis, the research is considered to be robust against publication bias and scientifically justifiable (Mueller et al., 2018).

**Table 4.** Classification table of effect sizes based on scale

Effect size	Classification
$\leq 0.10$	Small
$0.10 < \text{effect size} < 0.40$	Medium
$\geq 0.40$	Large

## RESULTS AND DISCUSSION

Based on the search results that meet the specified inclusion criteria (table 1), there are 59 studies eligible for further analysis. Table 3 presents the statistical characteristics of the research sample published from 2020 to 2024. There are forty-eight studies ( $n = 48$ ) categorized as large correlation, and eleven studies ( $n = 11$ ) categorized as medium correlation.

**Table 5.** Fixed and random effects

	$Q$	$df$	$p$
Omnibus test of Model Coefficients	243.778	1	<.001
Test of Residual Heterogeneity	2151.672	58	<.001

The results of this analysis indicate that the 59 effect sizes of the analyzed studies are heterogeneous ( $Q = 243.778, P < 0.001$ ). Thus, the Random Effect model is more suitable for estimating the mean value of the effect size from the 59 analyzed studies. These findings suggest the potential to investigate a moderator variable that could influence the relationship between technology mastery, pedagogical skills of teachers, and mathematics learning outcomes.

**Tabel 6. Coefficients**

	Estimate	Standard Error	z	p
intercept	0.757	0.048	15.613	< .001

Of the 59 studies, the linear model coefficient shows an estimation of 0.757, with a standard error of 0.048. The analysis results show that the z-value is 15.613, and the p-value is less than 0.001, indicating very high statistical significance ( $p < .001$ ). This indicates that digital technology mastery and pedagogical skills of teachers significantly influence mathematics learning outcomes. Based on the Forest Plot (see Appendix A), it can be observed that the effects of the analyzed studies vary in magnitude from 0.17 to 1.92. This indicates a significant variation in the effect sizes across studies, further emphasizing the need for considering context-specific factors when interpreting these results.

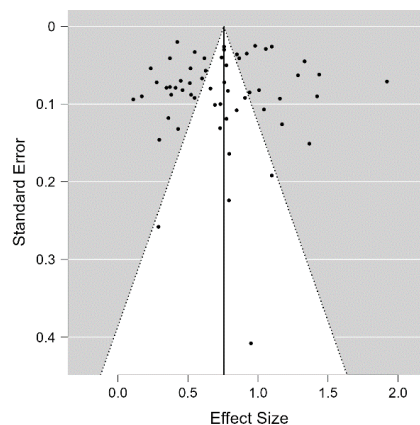
### Funnel Plot Asymmetry Test

To assess the potential presence of publication bias, a funnel plot asymmetry analysis was conducted using both the rank correlation test (Kendall's  $\tau$ ) and Egger's regression test. The result of the rank correlation test indicated a  $\tau$  value of 0.015 with a p-value of 0.870 (Table 8), suggesting no statistically significant correlation between effect size and standard error. This implies that there is no evidence of funnel plot asymmetry. Therefore, based on both Kendall's  $\tau$  and Egger's test, the analysis does not reveal significant publication bias in this study.

**Table 6. Fail-Safe N**

File Drawer Analysis			
	Fail-safe N	Target Significance	Observed Significance
Rosenthal	201068.000	0.050	< .001

Since  $K = 59$ , then  $5K + 10 = 5(59) + 10 = 305$ . The Fail-safe N value obtained is 201068, with a significance target of 0.05 and  $P < 0.001$ . Since the Fail-Safe N value  $> 5k + 10$ , it can be concluded that there are no publication bias issues in this meta-analysis study.



**Figure 1. Funnel Plot**

### Discussion

Based on the results of the meta-analysis covering 59 studies on the influence of digital technology mastery and pedagogical knowledge of teachers on mathematics learning outcomes, there is significant heterogeneity among the analyzed studies. This heterogeneity is reflected in the variation of effect sizes, ranging from 0.17 to 1.92. This substantial variation indicates that although most studies show positive effects, the outcomes vary depending on the specific context of each study.

The analysis of the linear model coefficient in this study indicates that the relationship between teacher technology mastery and mathematics learning outcomes has a very high impact. These findings are supported by Demissie et al., (2022), who showed that improving teachers' digital competence and effectively integrating technology enhances the quality of teaching and student performance. Petko (2012) also found that teacher willingness, skills, and tool availability positively influence technology use in the classroom. The professional

development process in information and communication technology also has a positive effect on teachers' confidence in pedagogical content knowledge for 21st-century learning and lesson design practices (Koh et al., 2017).

However, while technology can make the learning process more efficient and effective, not all teachers integrate technology into their teaching. Some inhibiting factors include integrating technology into curriculum design, network access, time, and other factors (Pittas & Adeyemi, 2019). Furthermore, Bischoff (2024) explains that teachers would benefit from increased support and resources to implement virtual mathematics curricula and effectively communicate with the class.

Although the variety of research results above shows significant results, further analysis is still needed. Lawless & Pellegrino (2007) indicate that there is still much to be improved and further solutions are needed in developing effective technology skills for mathematics teachers, especially those that have a direct impact on mathematics learning (Ahadi et al., 2024; Sanusi et al., 2023; Sun et al., 2023).

The Forest Plot presented in the analysis shows that the effects of the analyzed studies vary, with effect sizes ranging from 0.17 to 1.92. This indicates a significant variation in the effects of each study, although overall, the effects tend to be positive. This emphasizes the importance of considering the specific context of each study when interpreting the results of this meta-analysis.

The residual heterogeneity estimation, indicated by the  $\tau^2$  value of 0.129 and  $I^2$  value of 97.849%, shows significant variation in sample size effects among the 59 study results. The high  $I^2$  value indicates that most of the total variation among the study results is due to actual heterogeneity, not random error. Therefore, these results emphasize the need for further meta-analysis to identify factors that may act as moderator variables in the relationship between technology mastery, teacher pedagogy, and mathematics learning outcomes.

The asymmetry test of the funnel plot indicates no significant evidence of publication bias in this study. The results of Kendall's  $\tau$  test with a value of 0.015 and  $p = 0.870$ , as well as Egger's regression test showing a value of  $z = -0.281$  with  $p = 0.779$ , indicate symmetric data distribution. Thus, it can be concluded that the results of this meta-analysis are not influenced by publication bias, which further strengthens the validity of these findings. The large Fail-safe N (201,068) indicates that more than two hundred thousand additional studies with null results would be required to nullify the observed significant effects, confirming the robustness of the meta-analytic findings. This indicates that the results of this meta-analysis are highly robust and not easily influenced by unpublished or ignored studies. In other words, despite a significant number of additional studies with negative results, the overall conclusion of this meta-analysis remains valid.

## CONCLUSION

This meta-analysis revealed a strong and statistically significant relationship ( $r = 0.76$ ,  $p < .001$ ) between teachers' digital technology mastery, pedagogical competence, and mathematics learning outcomes. Based on the findings of this study, several implications can be drawn. First, professional development for teachers, with a focus on enhancing both digital technology skills and pedagogical competence, is crucial for improving mathematics learning outcomes. Second, further research is necessary to identify moderator variables that may influence this relationship, such as contextual factors, teacher characteristics, or individual student differences. Third, educational policies that support the integration of technology into teaching and the enhancement of teacher pedagogical skills should be promoted to maximize their positive impact on student learning outcomes.

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