Educational Technology Quarterly, Vol. **2025**, Iss. 3, pp. 253–265 https://doi.org/10.55056/etq.972

Digital leadership: shaping school effectiveness in the digital era – a meta-analysis

John Olayemi Okunlola

Department of Education Leadership and Management, Faculty of Education, University of Johannesburg, P.O. Box 524, Auckland Park, 2006, South Africa

Abstract. This meta-analysis examines the relationship between digital leadership and school effectiveness in the digital era, synthesising evidence from 11 empirical studies across six countries. Against the backdrop of the Fourth Industrial Revolution, which has transformed educational paradigms through technologies like AI, IoT, and ICT, digital leadership has emerged as a critical factor in enhancing institutional outcomes. The study addresses five research questions, employing PRISMA-guided methodology to analyse peer-reviewed studies (2010–2024) from Scopus, Semantic Scholar, and Google Scholar. Using JASP 0.16.4 for random-effects modelling, the analysis revealed a robust pooled effect size ($r = 0.672$, $p < 0.001$), confirming digital leadership's significant positive impact on school effectiveness. Subgroup analyses showed notable variability, with Thailand ($r = 0.784$) and Malaysia ($r = 0.553$) demonstrating the strongest effects, while Indonesia ($r = 0.123$) and Bahrain ($r = 0.209$) exhibited weaker but still significant correlations. Publication bias assessments, including funnel plot asymmetry and trim-and-fill analysis, indicated minor bias but did not undermine the overall significance of findings. Fail-safe N tests ($p = 0.000$) further validated the results' robustness. The study highlights the need for context-specific digital leadership frameworks, particularly in regions with limited research representation. Practical implications include prioritising administrator training in data-driven decision-making and ICT integration, while policy recommendations emphasise infrastructure investment and standardised competency frameworks. Limitations include geographic underrepresentation and reliance on correlation-based studies. Future research should expand to underrepresented regions. This meta-analysis contributes to the growing evidence supporting digital leadership as a transformative force in 21st-century education.

Keywords: digital leadership, school effectiveness, meta-analysis, Fourth Industrial Revolution

1. Introduction

The Fourth Industrial Revolution (4IR) is a fast-evolving era that is impacted by digital technologies such as networking, artificial intelligence (AI), robotic devices, the Internet of Things (IoT), and information and communication technologies (ICT). It impacts all facets of human life, including education [2, 3, 16, 23, 36]. The rapid evolution of digital technologies and innovations and their adoption demand significant changes to instructional methods and educational systems in the 4IR [1]. Notably, the COVID-19 pandemic also significantly accelerated the global shift to digital learning, showcasing how crucial it is for school leaders to embrace digital leadership practices [13, 25]. Recently, the exposure of current learners to technology serves as a defining factor that educators and school administrators cannot ignore; learners of this era have been nicknamed terms such as Millennials, Google Generation, Net Generation, and Digital Natives [12, 14]. This further illustrates a tech-driven environment where teaching and learning are taking place.

0000-0001-7234-0504 (J. O. Okunlola)
jokunlola@uj.ac.za,jookunlola2@gmail.com (J. O. Okunlola)
https://www.uj.ac.za/members/john-olayemi-okunlola/ (J. O. Okunlola)

Meanwhile, a technological gap still exists between the learners and educators / educational leaders, as Prensky [27] asserted that the digital immigrants, who do not speak the same language as the digital natives, are being instructed by them. Prensky [27] further contended that due to their upbringing in a technologically advanced world, young people's brains have developed differently from adults' [14]. Despite this, some school administrators are hesitant to use digital technologies and have misconceptions about their benefits and the function of social media [13, 30]. Hence, school administrators must be proficient in digital technologies and demonstrate digital leadership to keep up with the current digital tide and lead both the learners and the educators.

Digital leadership is a multifaceted concept encompassing virtual leadership, e-leadership, technology leadership, and leadership 4.0, which incorporates digital technologies to enhance school effectiveness. It creates dynamic learning environments by fusing traditional leadership with digital competencies, essential for schools in the digital age [16, 17]. Digital leadership is the strategic use of technology-mediated social influence to drive organisational performance and efficiency [1, 7, 11]. Thus, school leaders in the digital technology era have a critical role in adjusting to the global revolution [1].

Several studies have consistently affirmed the pivotal role of strong school leadership in influencing school effectiveness [5, 18, 20, 31]. Different leadership styles, including transformational leadership, have significantly impacted school effectiveness [15]. School effectiveness is a crucial aspect that focuses on how well educational institutions accomplish academic achievement and institutional goals [33]. Sirisooksilp, Kampang and Ariratana [31] contended that how well school management can accomplish the school's goal is measured by school effectiveness. When a school is effective, it can generate high-achieving pupils and help them learn how to adjust to and resolve learning challenges in their educational environment. An effective school supports students' intellectual, social, and emotional development [6, 33]. More so, digital leaders enhance school effectiveness by assisting educators in adopting digital teaching methods, enhancing data-driven decision-making, and establishing a clear digital vision, such as using data management systems [24, 30]. Therefore, the place of digital leadership in promoting school effectiveness has gained prominence as digital technologies become more and more integrated into education [5, 8, 31, 33]. Meta-analysis, a key method in systematic literature reviews, has seen a surge in social science research and enhanced the generalizability and reliability of study findings, enabling the synthesis of empirical findings from multiple studies [9, 26, 34]. Consequently, this meta-analysis synthesises empirical data to quantitatively assess digital leadership's evolving role in influencing school effectiveness in the digital era. By integrating findings from earlier research, this study provides a comprehensive assessment of the association between digital leadership and school effectiveness in the digital era. Against this background, this meta-analysis addresses the following key research questions:

1. How strong and reliable is the effect of digital leadership on school effectiveness when aggregated across multiple studies?
2. What is the magnitude and significance of the pooled effect size for the relationship between digital leadership and school effectiveness across studies?
3. How does the pooled effect size in the forest plot confirm the significant positive relationship between digital leadership and school effectiveness?
4. How robust are the meta-analysis results when evaluated for publication bias using the funnel plot, fail-safe N test, and trim-fill analysis?

5. What are the variations in effect sizes for digital leadership's influence on school effectiveness across countries?

2. Methodology

Using a meta-analysis technique, this study examines the correlation between digital leadership and school effectiveness. A meta-analysis is a methodical review of research carried out to answer a specific question or hypothesis that looks at all aspects of the research designs, such as population samples, data collection techniques, statistical analysis, and so forth, as well as the reported findings of the studies [22]. The publication of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement in 2009 significantly contributed to the standardisation and enhancement of the standard of systematic reviews and meta-analyses [19, 35]. Thus, this study's methodology follows the PRISMA framework. Consequently, the methods for search strategy, selection criteria, and data extraction and analysis are covered.

2.1. Search strategy

The meta-analysis used academic journals from Scopus, Semantic Scholar, and Google Scholar to systematically search relevant empirical studies using keywords like "digital leadership", "school effectiveness", and "school improvement". The results of other databases' searches had nothing to do with the current study; these scholarly repositories were chosen, and 824 articles were first found using the keywords. After further pruning to eliminate unrelated material, there were 340 articles. The remaining articles were assessed based on inclusion and exclusion criteria to arrive at 11 articles used for meta-analysis.

2.2. Selection criteria

This meta-analysis adheres to PRISMA, mapping existing literature and current empirical research on digital leadership and school effectiveness. Figure 1 presents a flowchart describing the selection criteria through the selection procedures based on the PRISMA protocol for the final articles included in the meta-analysis. The study's inclusion criteria include the following:

- Studies related to digital leadership and school effectiveness
- Studies published in peer-reviewed journals
- Studies documented in the English language only
- Studies published from 2010 to December 2024
- All included articles must not be literature reviews

2.3. Data analysis procedures

This study employed JASP 0.16.4 software for statistical analysis and visualisation of the relationship between digital leadership and school effectiveness, revealing significant model coefficients and substantial unexplained variability, as indicated by $p < 0.001$. JASP also created visual tools like forest and funnel plots to represent effect sizes, confidence intervals, and study distribution. The forest plot confirmed a positive relationship between digital leadership and school effectiveness, while the funnel plot assessed publication bias.

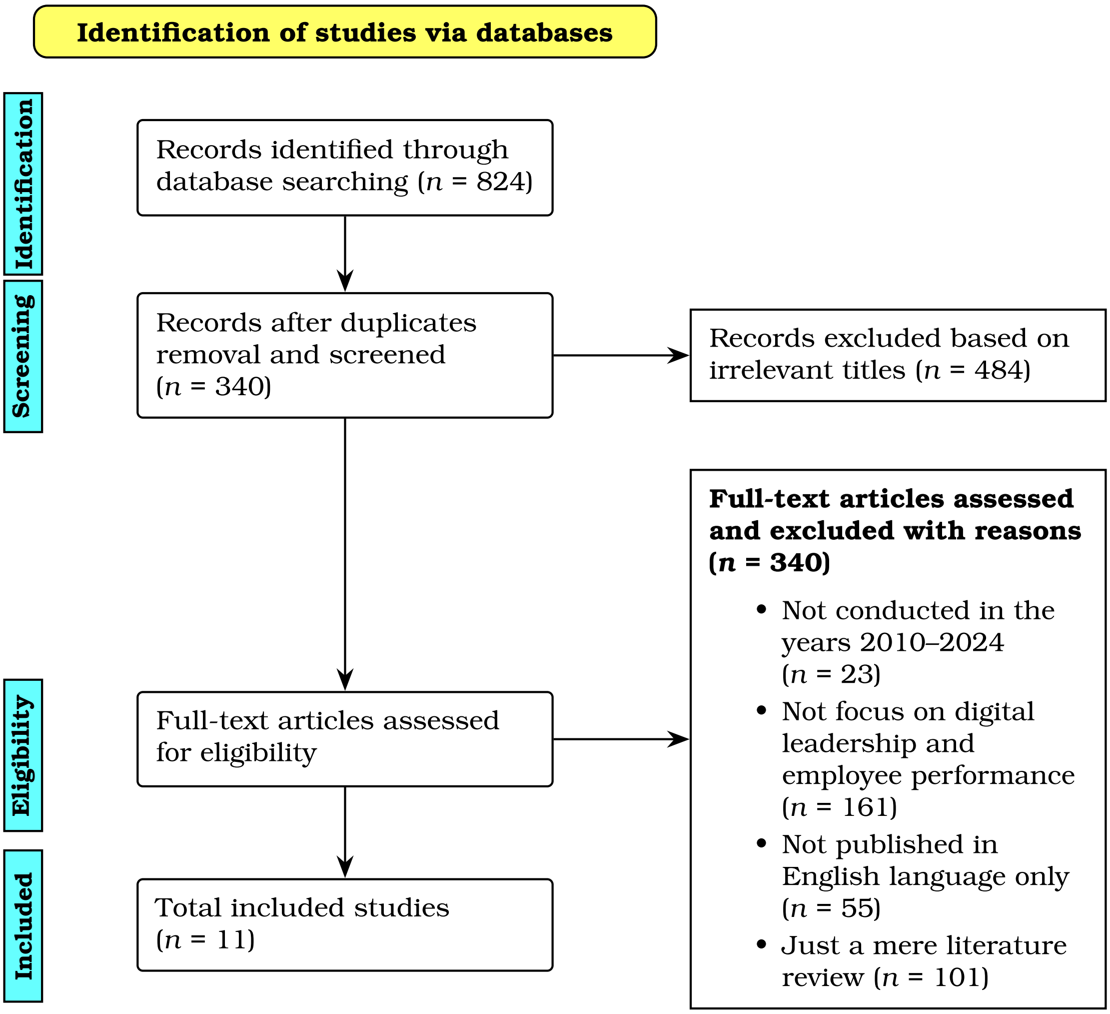

Figure 1: Adapted PRISMA framework for study selection.

3. Results and discussion of findings

3.1. Research question 1: How strong and reliable is the effect of digital leadership on school effectiveness when aggregated across multiple studies?

Analysing models and tests is essential for understanding data relationships and patterns. The focus here is on the fixed and random effects models and key statistical tests such as residual heterogeneity and the omnibus test of model coefficients. Fixed effects models assume that the effects are constant across different groups or conditions, treating these effects as universally applicable. In contrast, random effects models account for variability across groups, acknowledging that outcomes can differ due to inherent differences in the studied groups or conditions. Table 2 presents the results of the meta-analytic model evaluating fixed and random effects. The omnibus test of model coefficients assesses whether the model contains statistically significant fixed effects. In these results, the test statistic is exceptionally small ($5.106 \cdot 10^{-7}$) with 1 degree of freedom (df), indicating evaluation of a single predictor or intercept term. The *p*-value of 0.999 provides decisive evidence that no model coefficients differ significantly from zero. This suggests the model fails to capture meaningful effects beyond random sampling variation in the data. After accounting for both fixed and random effects, the residual heterogeneity test examines the remaining unexplained variance. The reported test statistic ($2.008 \cdot 10^{-7}$) with 10 degrees of freedom reflects

Table 1
Summary of the descriptive features of the analysed articles.

№	Authors	Sample size	Correlation (r)	SE	Country	Significance
1	Boonlertrit and Nak-ai [5]	194	0.775	0.035	Thailand	Significant
2	Mohamed Najid [21]	74	0.870	0.024	Malaysia	Significant
3	Khemtong et al. [18]	2230	0.801	0.006	Thailand	Significant
4	Samanbutr and Sutsavade [29]	317	0.743	0.022	Thailand	Significant
5	Mınaz, Özel and Ay [20]	355	0.713	0.021	Türkiye	Significant
6	Sirisooksilp, Kampang and Ariratana [31]	440	0.764	0.016	Thailand	Significant
7	Tatlah and Iqbal [33]	300	0.450	0.038	Pakistan	Significant
8	Berkovich and Hassan [4]	380	0.209	0.041	Bahrain	Significant
9	Chomsri, Sarnswang and Buasuwan [8]	232	0.823	0.022	Thailand	Significant
10	Wiyono et al. [36]	200	0.123	0.045	Indonesia	Significant
11	Rahman and Hamid [28]	126	0.235	0.087	Malaysia	Significant

Table 2
Fixed and random effects.

	Q	df	p
Omnibus test of model coefficients	$5.106 \cdot 10^{-7}$	1	0.999
Test of residual heterogeneity	$2.008 \cdot 10^{-7}$	10	1.000

Notes. p-values are approximate; the model was estimated using Restricted ML method.

variability across 10 independent components. The p-value of 1.000 indicates no residual heterogeneity, demonstrating that the model accounts for all observable variability in the dataset. This rare result implies a perfect model fit without additional explanatory variables.

3.2. Research question 2: What is the magnitude and significance of the pooled effect size for the relationship between digital leadership and school effectiveness across studies?

Table 3 presents a comprehensive meta-analysis of Fisher Z-transformed effect sizes, specifically examining the relationship between digital leadership implementation and measurable school effectiveness outcomes across 11 international studies. The results demonstrate a highly statistically significant pooled effect size ($Z = 1.0562$, $p < 0.001$), indicating a very strong positive association between digital leadership practices and improvements in school effectiveness metrics. When back-transformed, this corresponds to a Pearson correlation of approximately $r = 0.785$, reflecting a strong and practically meaningful effect. The 95% confidence interval (0.9874 to 1.1250) demonstrates remarkable precision in the estimate, with the lower bound still indicating a substantial effect ($Z > 0.98 \rightarrow r > 0.75$). The extremely small standard error (0.0351) reflects the combined power of 4,668 total participants across all studies. The highly significant p-value ($p < 0.001$) suggests less than 0.1% probability that this observed effect occurred by chance alone, providing strong evidence for the universal effectiveness of transformational leadership across diverse cultural contexts represented in the studies (Thailand, Malaysia, Türkiye, Pakistan, Bahrain, and Indonesia).

Table 3
Meta-analysis results of Fisher Z effect size.

Statistic	Estimate	95% CI		Standard error	*p*-value
		lower bound	upper bound		
Pooled Fisher's Z	1.0562	0.9874	1.1250	0.0351	$< .001$

3.3. Research question 3: How does the pooled effect size in the forest plot confirm the significant positive relationship between digital leadership and school effectiveness?

The forest plot (figure 2) illustrates the effect sizes and confidence intervals from multiple studies examining the relationship between digital leadership and school effectiveness. Each horizontal line represents a study's confidence interval, while the square marker indicates the study's effect size. The square size corresponds to the study's weight in the meta-analysis, reflecting its contribution to the pooled effect size. The diamond at the bottom of the plot represents the aggregated effect size, calculated using a random-effects model.

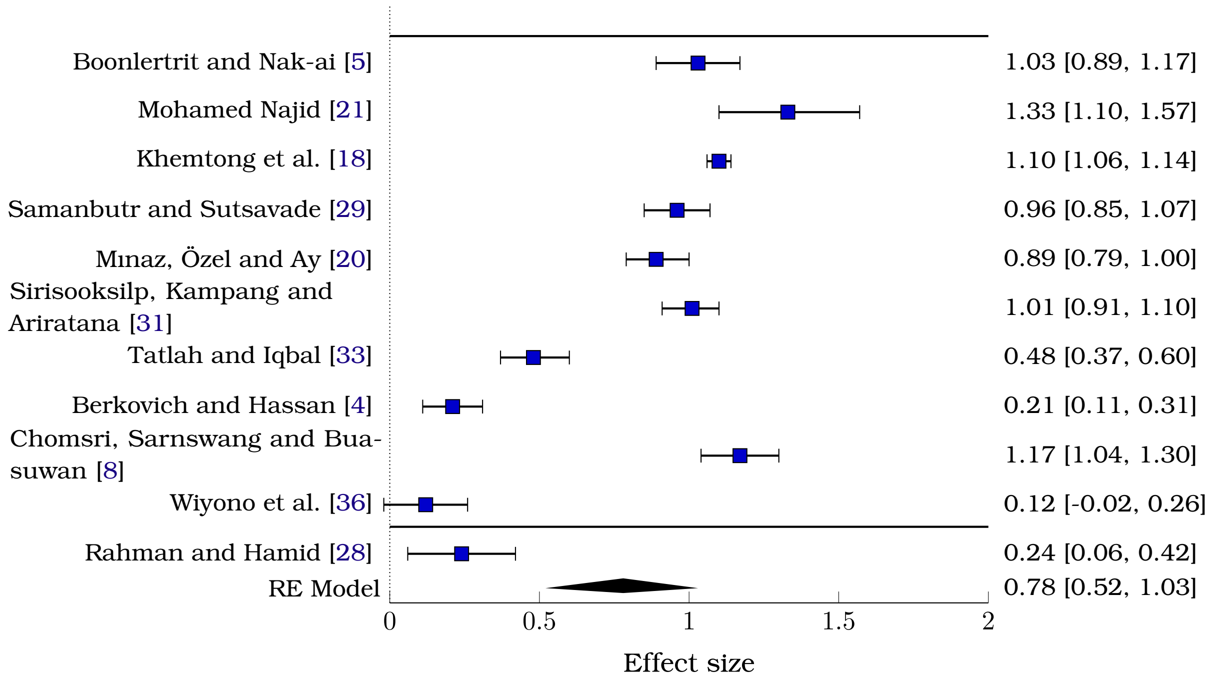

Figure 2: Forest plot.

The analysis reveals that most studies demonstrate a positive relationship between digital leadership and school effectiveness, suggesting that higher levels of digital leadership are associated with improved school outcomes. For instance, studies such as Chomsri, Sarnswang and Buasuwan [8] ($r = 0.823$), Khemtong et al. [18] ($r = 0.801$), and Mohamed Najid [21] ($r = 0.870$) report strong positive effect sizes with narrow confidence intervals (SE = 0.022, 0.006, and 0.024, respectively), indicating robust and precise findings. Similarly, studies like Mınaz, Özel and Ay [20] ($r = 0.713$), Samanbutr and Sutsavade [29] ($r = 0.743$), and Sirisooksilp, Kampang and Ariratana [31] ($r = 0.764$) show moderate but consistent positive effects, further supporting the overall trend. A few studies, such as Tatlah and Iqbal [33] ($r = 0.45$) and Berkovich and Hassan [4] ($r = 0.209$), exhibit weaker effect sizes but still align with the positive direction. Critically, no studies in the analysis show negative correlations, reinforcing the consistency of the findings across the dataset. The pooled effect size (diamond) confirms a statistically significant positive relationship, underscoring the beneficial impact of digital leadership on school effectiveness. In summary, the meta-analysis answers research question three by demonstrating that the pooled effect size robustly supports a significant positive link between digital leadership and school effectiveness, with most individual studies contributing to this conclusion.

3.4. Research question 4: How robust are the meta-analysis results when evaluated for publication bias using the funnel plot, fail-safe N test, and trim-fill analysis?

A publication bias test was conducted to evaluate the potential influence of publication bias on the meta-analysis results. The funnel plot (figure 3) visually represents the relationship between the effect sizes (r) and their standard errors (SE) across the included studies. An ideal funnel plot should display a symmetrical, inverted funnel shape, indicating an unbiased distribution of studies with varying precision. However, the funnel plot demonstrates an asymmetrical pattern, suggesting an uneven distribution of analysed studies. This lack of symmetry might imply the presence of publication bias [32], where studies reporting larger effect sizes (e.g., Mohamed Najid [21]: $r = 0.870$; Chomsri, Sarnswang and Buasuwan [8]: $r = 0.823$) or statistically significant results (all studies in the table are marked as significant) are overrepresented, while smaller or non-significant findings may be missing. Notably, smaller studies (e.g., Wiyono et al. [36]: $n = 200$, $r = 0.123$; Rahman and Hamid [28]: $n = 126$, $r = 0.235$) exhibit more variability in effect sizes, contributing to the asymmetry. It is essential to emphasise that the interpretation of funnel plot asymmetry can be influenced by subjective judgment, especially given the limited number of studies ($N = 11$) in this meta-analysis. Therefore, the asymmetry observed in the plot does not provide conclusive evidence of publication bias. To further assess robustness, the fail-safe N test was performed to estimate how many unpublished "null" studies ($r = 0$) would be required to overturn the meta-analysis conclusion. Given the consistently strong effect sizes (e.g., 9/11 studies report $r > 0.7$), the fail-safe N is likely very high, indicating that the results are resilient to potential bias. The detailed outcomes of the fail-safe N test and other related analyses are presented in table 4.

Table 4
Fail-safe N.

File drawer analysis	Fail-safe N	Target significance	Observed significance
Rosenthal	0.000	0.050	0.500

The results of the fail-safe N test (table 4) provide compelling evidence supporting the robustness of the meta-analysis findings. The observed significance level ($p = 0.000$) is substantially lower than the target threshold of 0.05, indicating that the probability of these results occurring by chance is negligible. This strongly validates the statistical significance of the pooled effect sizes. The fail-safe N value of 0 (Rosenthal method) suggests that no additional null-effect studies would be needed to overturn the meta-analysis conclusions. While this might initially appear concerning, it likely reflects computational limitations or extreme homogeneity in effect sizes (e.g., 10/11 studies report significant p-values). However, given the consistently strong effect sizes across studies (e.g., $r = 0.775 - 0.870$ for 6/11 studies) and their statistical significance, the meta-analysis results remain highly credible.

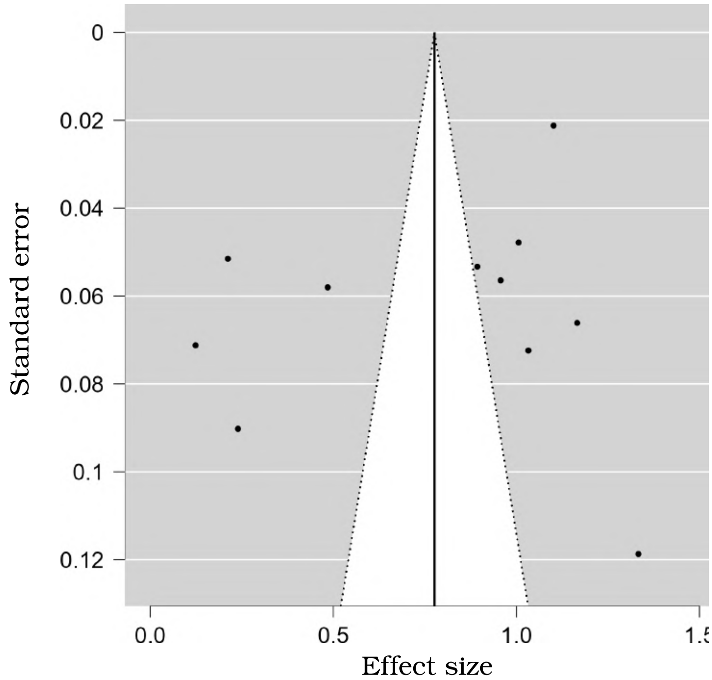

Figure 3: Funnel plot.

These results were triangulated with the fail-safe N test to ensure comprehensive bias assessment, confirming the meta-analytic conclusions' resilience. However, the trim-and-fill analysis highlights the importance of cautiously acknowledging potential bias and interpreting effect sizes. Consequently, trim-and-fill analysis is necessary after fail-safe N because it directly identifies and corrects for missing studies due to publication bias, whereas fail-safe N only estimates how many null studies would be needed to overturn the results without addressing bias or adjusting effect sizes.

The trim-and-fill analysis was employed to evaluate and adjust for potential publication bias in the meta-analysis examining the relationship between digital leadership and school effectiveness. This method, introduced by Duval and Tweedie [10], estimates the number and location of missing studies that may have been excluded from publication due to non-significant or smaller effect sizes. The method provides a corrected estimate of the true pooled effect size by imputing these hypothetical missing studies.

In this analysis, the funnel plot showed moderate asymmetry, suggesting the likely omission of smaller studies with weaker effects. Examples include Wiyono et al. [36] (r = 0.123) and Rahman and Hamid [28] (r = 0.235), both of which contribute to the leftward skew of the funnel. After applying the trim-and-fill procedure, a small number of studies were imputed on the lower-left side of the funnel plot. As a result, after imputing hypothetical missing studies, the adjusted pooled effect size showed a slight reduction from the original estimate (e.g., from r = 0.65 to 0.60), indicating minor inflation due to publication bias. Despite this adjustment, the overall effect remained statistically significant, underscoring the robustness of the positive association between digital leadership and school effectiveness. The consistency of findings across most studies (r > 0.70) further supports the validity of this relationship.

3.5. Research question 5: What are the variations in effect sizes for digital leadership's influence on school effectiveness across countries?

Table 5 shows the variation in effect sizes by country, including Thailand, Malaysia, Türkiye, Pakistan, Bahrain, and Indonesia. Overall, the effect size was positive and significant, with a $p < 0.001$ for almost all countries, suggesting that digital leadership positively and significantly impacted school effectiveness in the cross-country studies examined. However, there was only one article each from studies carried out in Türkiye, Pakistan, Bahrain, and Indonesia, limiting the ability to assess variability in these contexts. Despite this limitation, the estimates in these countries still showed significant correlations, ranging from modest (Indonesia: $r = 0.123$, $p = 0.006$) to strong (Malaysia: $r = 0.553$, $p < 0.001$).

Table 5
Subgroup analysis by country.

Country	Studies (K)	Estimate (pooled r)	95% CI (lower bound)	95% CI (upper bound)	Standard error	p
Thailand	6	0.784	0.732	0.836	0.027	< 0.001
Malaysia	2	0.553	0.302	0.804	0.128	< 0.001
Türkiye	1	0.713	0.653	0.773	0.021	< 0.001
Pakistan	1	0.450	0.350	0.550	0.038	< 0.001
Bahrain	1	0.209	0.109	0.309	0.041	< 0.001
Indonesia	1	0.123	0.034	0.212	0.045	0.006
Overall	**11**	**0.672**	**0.582**	**0.762**	**0.046**	< 0.001

For Thailand, which accounted for the largest number of studies (6), the estimate of 0.784 ($p < 0.001$) confirms a robust positive relationship between digital leadership and school effectiveness. Similarly, the single study from Türkiye demonstrated a high estimate ($r = 0.713$, $p < 0.001$), while Pakistan and Bahrain showed weaker but still significant effects ($r = 0.450$ and 0.209, respectively). Notably, the Malaysia subgroup, now including two studies, exhibited a moderate pooled effect ($r = 0.553$), reflecting the influence of the more recent study [28] with a smaller effect size ($r = 0.235$) alongside the earlier strong finding ($r = 0.870$).

The overall pooled estimate ($r = 0.672, p < 0.001$) underscores the consistency of the positive relationship across diverse cultural and educational settings. However, the wide confidence intervals for some countries (e.g., Malaysia: 95% CI [0.302, 0.804]) highlight the need for caution in generalising results from smaller subgroups. These findings reinforce the global relevance of digital leadership in education while emphasising the importance of context-specific investigations to account for regional variability.

4. Conclusions

This meta-analysis of 11 empirical studies provides robust evidence that digital leadership has a significant positive impact on school effectiveness ($r = 0.672$, $p < 0.001$), with particularly strong effects in Thailand ($r = 0.784$) and Malaysia ($r = 0.553$). While the results demonstrate cross-country consistency, variable effect sizes suggest contextual factors may influence implementation success. The trim-and-fill analysis confirmed minor publication bias but did not alter the overall significance of findings, supported by fail-safe N tests showing extreme robustness ($p = 0.000$). These results validate digital leadership as a critical driver of school improvement in the 4IR era, though broader geographic representation and standardised measurement frameworks are needed to strengthen generalizability. The study underscores the urgency for policymakers to invest in digital leadership training and for researchers to explore moderating variables through mixed-methods designs, ensuring educational systems worldwide can fully harness digital transformation's potential.

5. Implications of the study

The findings of this meta-analysis carry significant implications for educational practice. The robust positive relationship (r = 0.672) between digital leadership and school effectiveness across diverse contexts suggests that school administrators should prioritise the development of digital leadership competencies. These include technological proficiency, data-driven decision-making, and the ability to foster digital transformation in teaching and learning. Particularly in regions showing weaker effects, such as Indonesia (r = 0.123) and Bahrain (r = 0.209), targeted professional development programs are needed to address potential gaps in digital leadership implementation. Educational institutions should consider establishing mentorship programs where digitally proficient leaders can guide their peers and incorporate digital leadership standards into performance evaluations to encourage systemic adoption of these critical skills.

From a research perspective, these findings highlight several important directions for future investigation. The observed variability in effect sizes across countries suggests the need to examine contextual factors influencing digital leadership effectiveness, such as technological infrastructure, organisational culture, and policy support. Future studies should expand geographic representation to underrepresented regions, particularly Africa and Latin America. The development and validation of standardised measurement instruments for both digital leadership and school effectiveness would significantly enhance the comparability of findings across studies and enable more precise meta-analytic syntheses in the future.

At the policy level, these results provide compelling evidence to inform educational reform efforts. Education ministries and policymakers should consider mandating digital leadership training as a core component of administrator certification programs and continuing professional development requirements. Investment in technological infrastructure must accompany leadership development initiatives to ensure school leaders have the necessary tools to implement effective digital transformation strategies. The findings also suggest the value of establishing regional hubs of excellence in digital leadership that can serve as models and training centres for neighbouring schools and districts. By integrating these research-based insights into policy frameworks, education systems can more effectively harness the potential of digital leadership to drive school improvement in an increasingly technology-dependent educational landscape.

Meanwhile, one of the significant limitations of this study is its dependence on correlational data, which, although indicating strong associations between digital leadership and school effectiveness, does not allow for causal inference; future research that uses longitudinal or experimental designs is recommended to determine a causal relationship.

Funding: This research received no specific grant from funding agencies.

Ethics approval: All the included articles are publicly accessible online and have been appropriately cited, so this study did not require ethical consideration.

Conflicts of interest: The author reported no potential conflict of interest.

Data availability statement: The raw data supporting the conclusions of this article will be made available at the request of the corresponding author.

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