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REVIEW

The Information and Communication Technology Effectiveness for Enhancing Statistical Reasoning and Critical Thinking in the Statistical Instructional: A Meta-Analysis

La eficacia de las Tecnologías de la Información y la Comunicación para mejorar el razonamiento estadístico y el pensamiento crítico en la enseñanza de la estadística: un metanálisis

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ABSTRACT

Introduction: there is a substantial body of literature examining the use of Information and Communication Technology (ICT) and its relation to statistical reasoning and critical thinking. However, previous findings have been inconsistent, creating the need for a comprehensive synthesis.
Objective: the main purpose of this meta-analysis is to systematically investigate the overall impact of ICT on statistical reasoning and critical thinking skills in statistics education.
Method: the dataset comprises 25 publications released between 2016 and 2025. A random-effects model was employed for effect size estimation, with statistical calculations conducted using Comprehensive Meta-Analysis (CMA) software. The effect size was quantified using Hedges' formula.
Results: the findings indicate that ICT-based learning has a significant and positive impact (effect size = 1,043; $p < 0,05$) on students' statistical reasoning and critical thinking. Several moderating factors, including education level and class size, were found to play an important role in influencing the outcomes. However, there is insufficient evidence to suggest that geographical location significantly differentiates students' performance in ICT-based learning contexts.
Conclusions: this study highlights the effectiveness of ICT in enhancing statistical reasoning and critical thinking in statistics education. Mathematics educators are encouraged to integrate ICT strategically to support students' higher-order thinking skills.

Keywords: ICT; Statistical Reasoning; Critical Thinking; Meta-Analysis; Statistics.

RESUMEN

Introducción: existe un cuerpo sustancial de literatura que examina el uso de las Tecnologías de la Información y la Comunicación (TIC) y su relación con el razonamiento estadístico y el pensamiento crítico. Sin embargo, los hallazgos previos han sido inconsistentes, lo que genera la necesidad de una síntesis integral.

Objetivo: el propósito principal de este meta-análisis es investigar sistemáticamente el impacto general de las TIC en las habilidades de razonamiento estadístico y pensamiento crítico en la enseñanza de la estadística.
Método: el conjunto de datos comprende 25 publicaciones publicadas entre 2016 y 2025. Se empleó un modelo de efectos aleatorios para la estimación del tamaño del efecto, y los cálculos estadísticos se realizaron utilizando el software Comprehensive Meta-Analysis (CMA). El tamaño del efecto se cuantificó mediante la fórmula propuesta por Hedges.
Resultados: los hallazgos indican que el aprendizaje basado en TIC tiene un impacto significativo y positivo (tamaño del efecto = 1,043; p < 0,05) en el razonamiento estadístico y el pensamiento crítico de los estudiantes. Se encontró que varios factores moderadores, incluidos el nivel educativo y el tamaño de la clase, desempeñan un papel importante en la influencia de los resultados. Sin embargo, no existe evidencia suficiente para sugerir que la ubicación geográfica diferencie significativamente el rendimiento de los estudiantes en contextos de aprendizaje basado en TIC.
Conclusiones: este estudio resalta la efectividad de las TIC para mejorar el razonamiento estadístico y el pensamiento crítico en la educación estadística. Se alienta a los educadores de matemáticas a integrar estratégicamente las TIC para apoyar las habilidades de pensamiento de orden superior de los estudiantes.

Palabras clave: TIC; Razonamiento Estadístico; Pensamiento Crítico; Metaanálisis; Estadística.

INTRODUCTION

Mastering statistics demands robust cognitive skills, especially the intertwined abilities of statistical reasoning and critical thinking.[1,2] Together, these competencies guide learners in reading datasets, assessing evidence, and drawing sound decisions based on quantitative clues. Where statistical reasoning builds a coherent grasp of concepts such as variability and distribution, critical thinking sharpens the habit of questioning claims and spotting faulty inference. Yet many instructors encounter resistance because the discipline relies heavily on abstract principles that must be linked to real-life data exploration.[3]

Reasoning with data remains the bedrock that underpins trustworthy statistical thought. For that reason, educators are urged to select pedagogies that steadily advance learners' interpretive and deductive capacities.[4] Cultivating such reasoning goes beyond rehearsing formulas; it means guiding students to discover what the numbers actually signify in context.[5] When they succeed, learners can weave together graphs, summaries, and equations into a single, meaningful story rather than viewing each piece in isolation.[6]

Critical thinking, understood as the systematic, evidence-based process of analyzing, evaluating, and interpreting information to make sound judgments, lies at the core of statistics, shaping how researchers collect data, interpret results, and confront the integrity, reliability, and potential biases of the inputs before any calculation begins. Because datasets originate from diverse sources, each with its own quality and structure, a discerning mindset is crucial. When students engage in investigation, justification, and evaluation of a concept,[7] they do not simply crunch numbers; they challenge the integrity of the inputs, measure their reliability, and probe hidden biases before any calculation begins. As a result, their grasp of variation deepens, their analytical skills sharpen, and they progress beyond procedural users to thoughtful practitioners.[8] Because every statistical pathway exposes analysts to measurement error, nonresponse, or selective reporting, critical lenses naturally filter out sampling, confirmation, and selection bias, ultimately producing cleaner, more trustworthy estimates. Better analyses in turn support more professional and defensible policy and business decisions, shielding organizations from the costly pitfalls of overconfident yet flawed conclusions.[9]

In applied settings the power of statistics is often harnessed to uncover unexplored relationships among variables, but even promising associations can mislead if the analyst ignores the difference between correlation and causation. Critical thinking enables analysts to interpret research findings in light of the study's context, sample size, and statistical power, thereby avoiding overstated claims. In disciplines ranging from economics to public health and education, policymakers routinely lean on statistical evidence to guide choices. Relying on critical thought, however, helps to distinguish trustworthy data from misleading conclusions based on faulty premises.[10]

In educational settings, the rapid growth of information and communication technology (ICT) now offers a credible strategy for overcoming long-standing weaknesses in students statistical reasoning and critical-thinking practices in statistics. Studies indicate that when used purposefully, ICT correlates positively with enhanced critical-thinking scores, suggesting the tools usefulness beyond mere presentation.[11] This advantage arises because ICT operates simultaneously as a supportive infrastructure and as an interactive resource directed at learners.[12] When teachers incorporate features such as dynamic data visualizations, Monte Carlo simulations, and immediate links to datasets, students gain a step-by-step platform for reasoning about uncertainty and sampling arguments.

Evidence further points to heightened classroom energy and deeper conceptual exploration when ICT underpins statistical instruction, which, in turn, broadens learners grasp of how data patterns arise and why they matter.[13,14] Specialized software packages, mobile simulation apps, and cloud-based dashboards no longer serve simply as replacements for calculators; they immerse learners in experimental design, hypothesis testing, and graphical dis-play at comparable levels of sophistication with professional analysts, thereby lifting overall instructional quality.[15]

Nonetheless, reviews of the existing literature reveal that reported gains in statistical reasoning and critical thinking through ICT integration are inconsistent, varying with context, tool selection, and educator guidance. Meta-analysis is particularly valuable in this context because it consolidates disparate empirical studies and thus clarifies both the overall impact of information and communication technology on statistics learning and the variability of that impact across different settings. By aggregating data, the approach not only computes a summary effect size but also uncovers moderators-such as instructional design, course enrolment, and geographic region-that shape how and why technology influences student achievement.

Systematic reviews and meta-analyses have recently examined how information and communication technology (ICT) affects mathematics learning. Arlinwibowo and colleagues[16] synthesised data from fifty-two publications and found an average effect size of 1,13, which classifies it as large. This figure implies that lessons incorporating ICT consistently lift achievement well above what occurs in traditional classrooms. Likewise, Suparman and co-workers[15] aggregated seven studies focused on critical thinking and reported an effect size of 1,04, also large. That finding suggests that technology-rich environments sharpen students reasoning in mathematics more than standard practices do. Despite these encouraging results, both reviews overlook statistics learning and draw on regional samples whose characteristics are now out of date. In addition, they rarely account for moderating factors-such as learner age, instructor experience, or infrastructure quality-that might make blended learning more or less effective across diverse settings.

Given these gaps, the present study seeks a broad, up-to-date appraisal of ICTs role in shaping statistical reasoning and critical thinking during statistics courses. A meta-analysis provides a systematic summary of effect sizes from prior research, thereby illuminating both average gains and variability in learner outcomes; this evidence can inform the design of more targeted, evidence-based instructional innovations.

To address the gaps identified in the literature, the present investigation poses three interrelated questions:

RQ1: what overall treatment effect do ICT-enhanced instructional strategies exert on statistical reasoning and critical thinking, and how does that effect compare with conventional pedagogies?

RQ2: how do moderating variables-class size, grade level, and geographic setting-detail differential impacts of ICT interventions on students statistical reasoning and critical thinking?

Literature Review

Statistical Reasoning

Régnier et al.[2] describe statistical reasoning as a central aim of every serious statistics course. Conway et al.[4] strengthen that view, insisting that instructors make this line of thought visible in every lesson. To support the claim, Kusumarasdyati[18] argues that teachers must reinforce, not gloss over, the reasoning behind each new tool or concept. In plain terms, statistical reasoning is the skill needed to grasp a concept, analyse data, and explain what the numbers really mean. Makar et al.[19] add that such reasoning asks three big questions: What story does the data tell? Is there anything unusual in the pattern? Can I trust the conclusions I am ready to share?

Garfield[20] explains that statistical reasoning involves skills such as identifying patterns, understanding variability, testing hypotheses, and evaluating conclusions based on data. This concept includes several important aspects:

a. Descriptive Reasoning: the ability to describe data through tables, graphs, and measures of central tendency.
b. Inferential Reasoning: the ability to draw conclusions from sample data to predict a larger population.
c. Variability Reasoning: the ability to understand that data can vary and that this variation has meaning.
d. Contextual Reasoning: the ability to relate statistical results to real-world contexts.

While Garfield’s framework offers a valuable starting point, the literature is enriched by several alternative conceptualizations. Jones et al.[21] delineate a developmental trajectory, portraying statistical reasoning as evolving from intuitive, context-sensitive judgments toward more systematic, abstraction-laden processes. In a complementary vein, Wild et al.[22] advance a cyclic model of statistical thinking that explicitly links reasoning about data to a recursive sequence of question formulation, examination of variability, and contextual interpretation of findings. By contrast, Garfield’s paradigm is more circumscribed, prioritizing discrete cognitive achievements over the emergent, recursive behaviors characteristic of statistical inquiry. Nonetheless, its precision serves educators by delineating essential competencies that may otherwise remain hidden within broader models, and the two perspectives together underscore the value of situating discrete skill acquisition within an inquiry-driven, iterative investigative frame.

In educational settings, engaging with statistics does more than teach numbers; it sharpens students critical and analytical minds. Such reasoning is now vital, because the information age constantly asks people to read data closely and form sound judgments. When teachers weave technology, curriculum, and assessment together, they turn these tools into genuine partners in learning and boost learners statistical.[4] Multimedia resources, from guided simulations to real-time data dashboards, make abstract ideas tangible and memorable.

Alongside pedagogy, information technology opens the door to powerful analytical tools that turn raw data into insights. Programs such as Excel, SPSS, R, and several browser-based apps allow students to manipulate datasets, test hypotheses, and watch patterns emerge in virtual labs. Evidence indicates that learners who work with these platforms develop a clearer grasp of theory and are more confident applying it outside the classroom.[23,24,25]

Critical Thinking

Mathematical critical thinking describes a learners ability to dissect, judge, and resolve problems in mathematics using clear, step-by-step logic. Brandt et al.[26] offer a similar view, defining the skill as a mental process that breaks down information, weighs its worth, and draws reasoned conclusions. Their analysis highlights critical thinking as an essential tool for inquiry, one that lets people sift through data and arrive at sensible choices. Facione[27] lists six building blocks of this skill-interpretation, analysis, evaluation, inference, explanation, and self-regulation. In the context of statistics education, these components take on concrete forms: students must interpret data displays and problem contexts, analyze distributions and relationships among variables, evaluate the reliability of datasets and the validity of statistical claims, infer population parameters from samples, explain reasoning when justifying conclusions, and self-regulate by checking for computational errors or cognitive biases throughout the problem-solving process. Workplace research ranks it the top competency employers seek, confirming its broad value beyond the classroom.[28]

In schooling, and especially in courses on statistics and mathematics, critical thinking is key because many tasks require students to untangle messy problems and reach conclusions grounded in evidence.[26] Within statistics, the skill guides learners as they spot issues, weigh competing claims, check the reliability of numbers, and finish by stating accurate results. Put another way, it means examining data and formulas in a systematic way, asking what they really say instead of just accepting them. To do this, students must grasp key concepts, see how two or more variables relate, test whether a dataset is trustworthy, and then draw answers that outside facts can endorse.

Researchers have already looked at critical thinking in statistics classrooms from several angles.[8,29,30] They generally agree that targeted lessons, open discussions, and real-world datasets boost students ability to question numbers rather than memorize procedures.

Recent research investigates how to embed critical-thinking development intentionally in introductory statistics courses.[31] Their findings suggest that when instructors clarify statistical routines as problem-solving tools and encourage reflective questioning throughout the learning cycle, students gain both procedural competence and a more discerning analytical disposition. Similarly, Friedman, Green et al.[29] showed that weaving authentic statistical controversies into assignments prompts learners to evaluate evidence, assess biases, and articulate reasoned conclusions-rather than merely following formulaic steps. A comprehensive meta-analysis by Jones et al.[30] also confirms that collaborative project work and structured peer review accelerate cognitive transfer when learners interpret results, justify methods, and critique each other’s reasoning. In the digital age, these pedagogical strategies can be scaled-up meaningfully through targeted information and communication technology (ICT) integration.

ICT adds strategic value by replacing passive displays of summary data with dynamic and manipulable visualizations that reveal underlying distributions, trends, and uncertainty.[32] Cloud-based statistical suites, augmented-reality plots, and tablet-enabled touchscreen dashboards now empower students to run Monte Carlo experiments, prototype hypothesis tests, or drill into sub-samples on the fly, fostering a habit of exploratory, evidence-driven reasoning. Tools like Jupyter notebooks, RStudio Cloud, or even in-browser spreadsheet macros further permit live annotation, timestamped code review, and immediate peer-feedback loops that model professional data-science workflows while reinforcing metacognitive awareness. Preliminary results from multi-institutional pilot studies indicate that participants who routinely engage with ICT-enhanced tasks outperform peers on standardized assessments of critical thinking, especially when the tasks require risk calibration, predictive modelling, or assessing causal claims in observational datasets. Collectively, the evidence supports a purposeful blend of active learning, authentic applications, and technology integration as an effective route to stronger, broader critical-thinking competencies in the statistics curriculum. Studies conducted over the last ten years consistently indicate that embedding information-and-communication technology in mathematics lessons meaningfully boosts learners abilities to think critically.

Moderating Factors

The persistently low level of statistical reasoning and critical thinking observed in many classroom statistics courses suggests that multiple moderating influences are at work, each shaping students' performance in indirect ways. In any given cohort some learners grasp concepts and apply reasoning deftly, while others struggle, leaving a large middle group whose progress is unpredictable. Because of this uneven distribution, systematic examination of the moderating influences is essential if educators hope to explain, and ultimately improve, overall learning outcomes.

Recent reviews of the literature, including work by Helsa et al.[33] and Tawaldi et al.[34], distinguish between two broad categories of moderating factor: substantial, which relate directly to learner or task characteristics (e.g., prior knowledge, class size, or educational level), and extrinsic, which reflect contextual or environmental conditions (e.g., instructional design, institutional support, or technology use). This distinction aligns with broader taxonomies of moderators in educational research, such as those outlined by Cheung et al.[35] and Hattie[36], which separate learner-centered variables from context-driven influences to clarify how different conditions shape learning outcomes. Helsa et al.[33] argue that substantial moderators correlate closely with the independent or dependent variables of interest class size, instructors formal education, access to digital tools, and students physical location. By contrast, extrinsic moderators publication year, document type, journal source, and database citation appear related to the larger research context but do not directly alter classroom learning. The present investigation therefore narrows its focus to the substantial factors, since they are the ones most likely to account for observed differences in learners statistical reasoning and critical thinking.

METHOD

Research Design

This investigation adopts a meta-analytic design and applies a random-effects model, thereby accommodating variations in class size, learner age, instructional platform, and geographic region.[37] An overview of the analytic workflow for this stage is displayed in figure 1.[38]

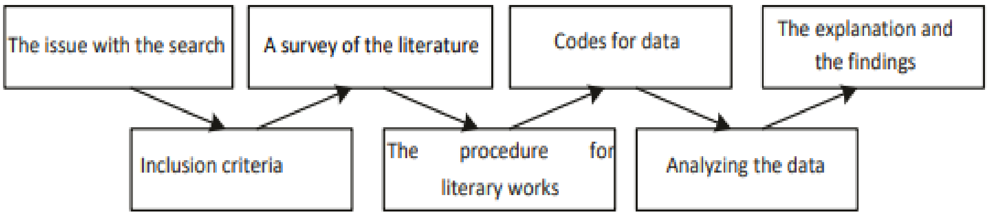

Figure 1. Phase diagram of the meta-analysis process

Inclusion Criteria

To maintain both academic rigor and practical relevance, researchers established a set of clear inclusion criteria that strictly outline which studies would enter the meta-analysis and which would be excluded. These benchmarks ensure that each selected report directly speaks to the research questions and offers the statistical information needed for pooled effect-size estimation. An overview of the final criteria appears in table 1 below.

Table 1. Research Inclusion Criteria

No.	Criteria	Inclusion
1	Population	Global student population
2	Intervention	Implementation of ICT-based learning as the main intervention strategy
3	Comparison	Traditional learning as the baseline for comparison
4	Outcome	Statistical reasoning and critical thinking as measured outcomes
5	Study Design	Experimental design with a control group
6	Statistical Data Availability	Statistical data available for both experimental and control groups
7	Peer-reviewed Sources	Peer-reviewed journal articles or conference publications
8	Publication Year Range	Published between 2016–2025
9	Full-text Accessibility	Full-text articles accessible online

Literature Search and Selection

The literature search was conducted across three major databases—Scopus, Semantic Scholar, and Google Scholar—using tailored query strings for each platform. In Scopus, the syntax applied was: TITLE-ABS-KEY (“ICT” AND “critical thinking” OR “statistical reasoning” OR “statistical learning” OR “meta-analysis” OR “e-learning” OR “information technology in education”). For Semantic Scholar, a broader keyword search was performed combining terms such as “ICT critical thinking”, “statistical reasoning skills”, and “meta-analysis in education”. In Google Scholar, advanced search options were used with Boolean operators, e.g., “ICT” AND (“critical thinking” OR “statistical reasoning”) AND “education”. From this process, the team retrieved 55 records from Scopus, 979 from Semantic Scholar, and 325 from Google Scholar. Eligibility and data extraction then proceeded according to the PRISMA framework (Preferred Reporting Items for Systematic Reviews and Meta-Analyses.[39] A flow diagram summarizing each stage of the screening and selection is provided in figure 2.[40]

Figure 2 presents the flowchart of the literature search following the PRISMA guidelines. Between 2016 and early 2025, a comprehensive sweep across multiple engines yielded 1359 articles. Running a standard deduplication program removed 128 records, yet some duplicates persisted because of subtle formatting differences, such as inconsistent phrasing and varied numerical styles. To address this, reviewers manually screened the set and carefully removed an extra 446 articles. What remained was checked again against the inclusion and exclusion criteria, paving the way for more focused analysis.

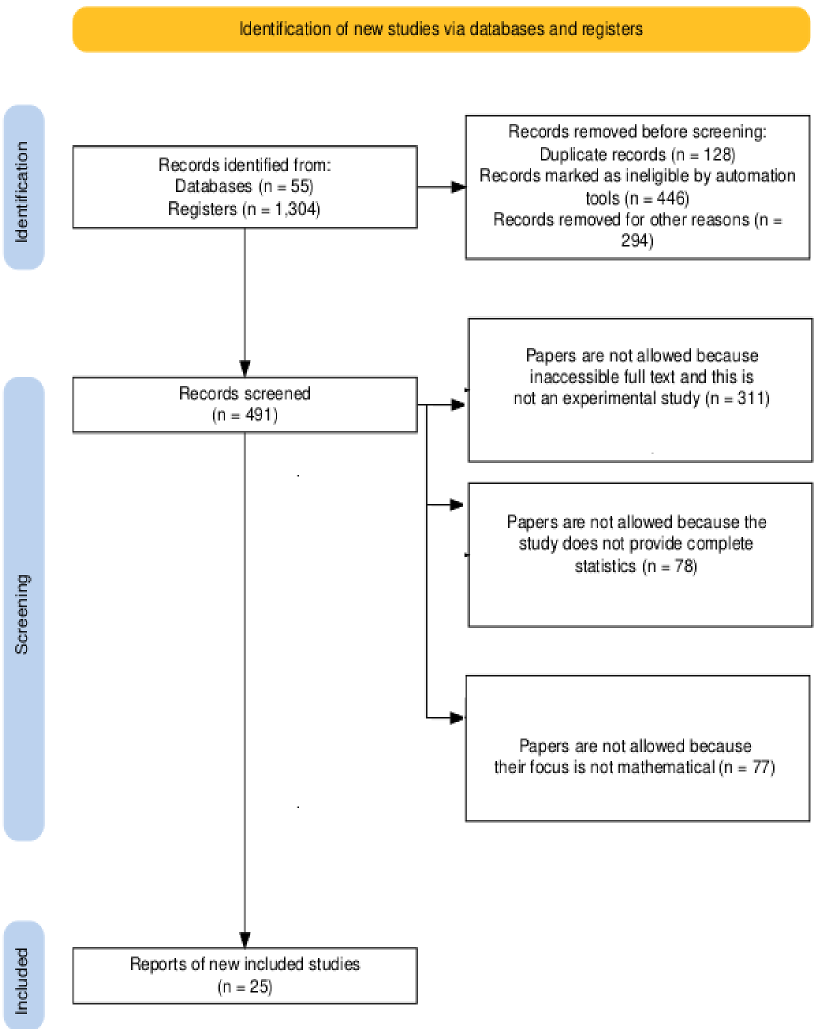

Figure 2. PRISMA diagram outlining the document selection process

Data Extraction

The meta-analysis relied on a detailed coding sheet that tracked fundamental details such as the reviewers identities, the publication year, class size, the participants educational level, and the study’s geographic setting. These entries were systematically entered into Microsoft Excel to create a central repository. In addition to the descriptive characteristics, the sheet captured crucial quantitative figures, including sample sizes for each experimental group, as well as their means and standard deviations. By documenting these diverse aspects, the research team aimed to strengthen the consistency and overall rigor of the final estimates. Two experienced meta-analysts then independently checked the data against the original articles to rule out transcription errors. After a thorough side-by-side comparison, their codes matched the research teams entries, providing further assurance that the dataset is both accurate and trustworthy.

Data Analysis

The current meta-analysis used Hedges' g as the primary index of effect size, a choice grounded in the small sample sizes often found in studies of ICT-based learning.[41] Following convention, these effect sizes were placed into distinct categories relying on Cohen's original benchmarks:[38]

- g = 0,00-0,20 indicates a small effect.
- g = 0,21-0,50 indicates a moderate effect.
- g = 0,51-1,00 indicates a substantial effect.
- g > 1,00 indicates a strong effect.

To further explore student outcomes, the researchers employed a Z-test to assess the influence of ICT-orientated learning on learners statistical reasoning and critical thinking.[31] They followed with Cochran s Q-test to investigate whether class size, grade level, learning platform, and geographic location shaped those same outcomes. The precise calculation used for Hedges g is presented in the equation that follows.[37]

$$g = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}}} \times \left(1 - \frac{3}{4df - 1}\right)$$

To investigate variability across the included studies, we initially applied Cochran's Q-test alongside the I2 statistic. The Q-test produced a value of 154 850 with 24 degrees of freedom (p < 0,001), confirming significant heterogeneity. In addition, the I2 value reached 85 %, suggesting that approximately 85 % of the variation in effect sizes reflects genuine differences among studies rather than random error. This substantial heterogeneity underscores the need to explore moderator variables that might explain the observed inconsistencies.

Accordingly, a moderator analysis examined class size, attainment level, delivery platform, and geographic region, clarifying the conditions under which blended learning yields its largest benefits. To evaluate the robustness of our results, we also examined publication bias and conducted sensitivity analyses, since no body of evidence is entirely shielded from selective reporting.[42] We employed funnel plots together with the trim-and-fill method to quantify any systematic under-reporting[41] and carried out the corresponding sensitivity checks using the Comprehensive Meta-Analysis (CMA) software.

RESULTS

Sensitivity Analysis and Publication Bias

To verify indications of publication bias, the distribution of effect size data was observed using a funnel plot (figure 3).

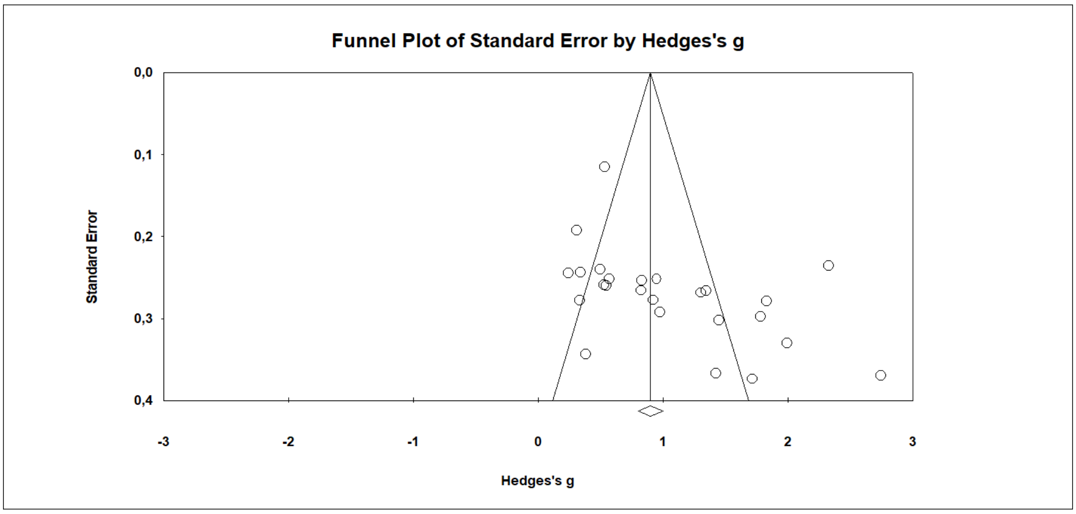

Figure 3. Distribution of effect size data in a

As shown in figure 3, the distribution of effect size data in the funnel plot appears symmetric. To confirm the symmetry of the distribution, a trim and fill test was conducted (table 2).

Table 2. Results of trim and fill analysis (Duval and Tweedie's trim and fill)

	Studies Trimmed	Fixed Effects			Random Effects			Q Value
		Point Estimate	Lower Limit	Upper Limit	Point Estimate	Lower Limit	Upper Limit	
Observed values		0,89960	0,80187	0,99732	1,04288	0,78759	1,29817	154,84986
Adjusted values	0	0,89960	0,80187	0,99732	1,04288	0,78759	1,29817	154,84986

As shown in table 2, every included effect size remained within the distribution, with no values falling outside either tail. Such a finding affirms a clear symmetric pattern in the funnel plot. Therefore, the dataset shows no hint of publication bias.[34]

The researcher undertook a sensitivity analysis designed to gauge the influence of potential outliers at both extremes of the effect-size spectrum. The findings identified a lowest value of g equal to 0,788 and a highest value of 1,298 across the twenty-five studies. Meanwhile, the pooled point estimate of g for that set sits at 1,043. Since 1,043 sits comfortably between 0,788 and 1,298, nothing exceeds these boundaries and none can be flagged as an outlier. This pattern suggests that changing the composition of the dataset, whether by adding or removing observations, is unlikely to alter the overall conclusion.[38]

Effect Size Estimation

Twenty-five qualifying studies entered the meta-analysis, collectively producing twenty-five effect-size estimates expressed in g and drawing on a sample of 1,889 students. The resulting effect sizes varied noticeably in sign, statistical significance, and magnitude (table 3).

Table 3. Results of Effect Size Calculation

Document	Effect Size (g)	P-Value
[43]	0,974 (0,402;1,547)	0,001
[44]	1,994 (1,348;2,640)	0,000
[45]	2,747 (2,022;3,472)	0,000
[46]	0,825 (0,304;1,346)	0,002
[47]	1,449 (0,857;2,042)	0,000
[48]	1,305 (0,779;1,832)	0,000
[49]	0,828 (0,331;1,326)	0,001
[50]	0,533 (0,306;0,759)	0,000
[51]	0,334 (-0,211;0,878)	0,230
[52]	0,948 (0,454;1,442)	0,000
[53]	0,529 (0,021;1,037)	0,041
[54]	1,780 (1,197;2,363)	0,000
[55]	0,382 (-0,291;1,054)	0,266
[56]	1,829 (1,283;2,376)	0,000
[57]	0,244 (-0,235;0,723)	0,318
[58]	1,343 (0,822;1,865)	0,000
[59]	2,325 (1,864;2,786)	0,000
[60]	1,422 (0,703;2,140)	0,000
[61]	0,548 (0,039;1,057)	0,035
[62]	0,571 (0,077;1,065)	0,024
[63]	0,338 (-0,139;0,816)	0,165
[25]	0,919 (0,376;1,463)	0,001
[64]	0,308 (-0,069;0,684)	0,110
[65]	0,496 (0,026;0,967)	0,039
[66]	1,714 (0,982;2,446)	0,000
Effect Size Estimate: 1,043 (0,788; 1,298), p = 0,000.		

Table 3 shows that the point estimate for the 25 effect size units is 1,043, indicating that the use of ICT has a strong positive impact on statistical reasoning and critical thinking. In addition, the significance level of the Z-test is below 0,05, indicating that ICT implementation has a statistically significant impact on improving these skills. This confirms that integrating ICT into mathematics instruction effectively enhances students’ statistical reasoning and critical thinking.

Subgroup Analysis

The Cochrane Q test was used to examine several moderating factors (e.g., education level, class size, and geographic location) that were hypothesized to distinguish statistical reasoning and critical thinking in statistics learning that incorporates ICT (table 4). Figure 4 offers a side-by-side view of effect sizes for different moderating factors that shape learners statistical reasoning and critical thinking in ICT-supported statistics classes. By mapping Education Level, Class Size, and Geographic Location on a single chart, the graphic adds a visual layer to the numbers shown in table 4, making the strength and direction of each influence easier to grasp at a glance.

Table 4. Cochrane Q Test Results

Factor	Group	Effect Size (g)	p-value
Education Level	Higher Education	0,913	0,000
	Senior High School	1,064	
	Junior High School	1,125	
	Elementary School	1,059	
Class Size	Large Class	0,974	0,000
	Small Class	1,124	
Geographic Area	Indonesia	1,041	0,000
	Outside Indonesia	1,033	

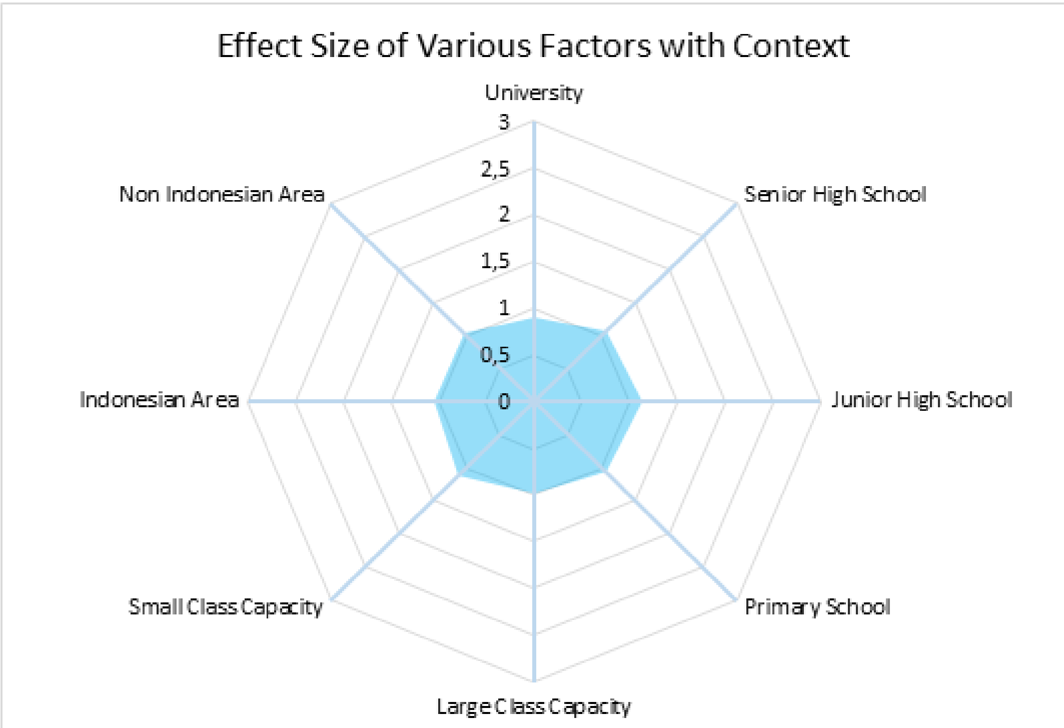

Figure 4. Radar Plot of Effect Sizes by Moderating Factors

Table 4 clearly shows that each of the three moderating variables-both home and school condition-contributes meaningfully to the relationship between ICT use and learners statistical reasoning and critical thinking:

- Students formal education level exerted the strongest influence, reaching the largest effect for junior-secondary learners (g = 1,125, p < 0,001), underscoring that younger adolescents may respond particularly well to technology-rich pedagogy.
- Reductive class size, too, proved influential, posting a nearly identical peak effect in small groups (g = 1,124, p < 0,001).

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Geographical context emerged as a stalwart moderator: Indonesias effect (g = 1,041) lay close to that of other national samples (g = 1,033), with both indices achieving high statistical significance (p < 0,001).

DISCUSSION

The present meta-analysis seeks to offer a thorough assessment of how information-and-communication-technology use influences students statistical reasoning and critical-thinking skills. It addresses

Effectiveness of ICT Use on Students' Statistical Reasoning and Critical Thinking

This meta-analysis review reveals that ICT-based learning has a very strong positive effect on improving students' statistical reasoning and critical thinking. Furthermore, it confirms that the implementation of ICT learning can significantly enhance both skills. The meta-analysis study evaluating the effectiveness of computer-assisted instruction in statistics learning found that interactivity and engagement in computer-based instruction can improve statistical understanding by encouraging deeper processing and reducing cognitive load.[67] Specifically, the meta-analysis by Sosa et al.[67] of 45 experimental studies found that computer-assisted statistical instruction provided a meaningful average performance benefit ($d = 0,33$).

Similarly, Tedla et al.[68], in a meta-analysis of 30 empirical studies, found that computer-supported collaborative learning (CSCL) had a significantly positive effect on students' critical thinking skills, with an overall effect size (ES) of 0,859 ($z = 8,55$, $p < 0,001$; 95 % CI (0,661–1,055)). These findings reinforce the conclusion of the current study, confirming that ICT-based learning significantly enhances students' mathematical statistical reasoning and critical thinking. This underscores the effectiveness of ICT-based learning in fostering these essential cognitive skills.

Numerous studies support the effectiveness of ICT in enhancing critical thinking abilities in statistics. For instance, a meta-analysis by Camnalbur et al.[69] found that the use of Computer-Assisted Instruction (CAI) in statistics education significantly improved students' analytical and interpretative skills. Another study by Benková et al.[70] also showed that technology-based collaboration led to deeper understanding of complex statistical concepts compared to traditional methods.

Overall, the integration of ICT in statistics education not only enriches the teaching and learning process but also improves students' critical thinking skills in understanding data, performing analysis, and drawing statistically valid conclusions. The use of Information and Communication Technology (ICT) in statistics education has become a popular approach to enhancing students' statistical reasoning and critical thinking. This meta-analysis demonstrates that ICT use has a positive and significant impact on the development of these two core competencies.

The use of statistical software, data simulations, and ICT-based interactive applications helps students visualize abstract statistical concepts. Interactive data visualizations, such as dynamic graphs and software-based simulations, assist students in intuitively understanding data distributions, probability concepts, and analysis of variance. Based on the meta-analysis findings, the average effect size (ES) of ICT-based interventions on statistical reasoning and critical thinking is 1,043 ($p < 0,000$), which falls under the large effect category. This finding is consistent with previous research that has shown interactive technologies can reduce students' cognitive load in understanding complex statistical concepts.[69]

Factors influencing this effectiveness include:

a. Duration of Intervention: long-term interventions (more than one semester) have more significant effects compared to short-term ones.

b. Problem-Based Learning (PBL) Approach: integrating ICT into PBL has proven to enhance students' exploration of real data, thereby strengthening statistical reasoning.

c. Computer-Based Simulations: simulation-based learning provides virtual experimental experiences that deepen students' understanding of data and probability.

Meanwhile, the effectiveness of ICT in improving critical thinking is evident in students' ability to analyze, evaluate, and draw conclusions based on statistically presented digital data. Technology-assisted learning, such as computer-supported collaborative learning (CSCL), contributes to the development of analytical discussions among students.

Key ICT elements contributing to enhanced critical thinking include:

a. Interactive Learning Tools: applications that allow deep exploration of concepts.

b. Collaborative Platforms: technology-based discussions that encourage students to defend data-driven arguments.

c. Online Assessment Tools: ICT-based evaluations that support in-depth reflection on errors and concept understanding.

Variations in Students' Statistical Reasoning and Critical Thinking in Statistics Learning

The present meta-analytic study investigates whether three moderating factors-educational level, class size, and geographic setting-systematically distinguish students ability to reason statistically and to think critically. Separate subsections that follow provide an in-depth account of each factor.

Education Level

The impact of ICT tends to be higher at secondary and higher education levels compared to elementary education. This is due to students' greater readiness to independently use technology and their more developed cognitive abilities. At secondary and higher levels, students generally already possess basic information technology skills, enabling them to utilize statistical software, data simulations, and analytical applications more effectively. Furthermore, students at these levels typically have a more mature understanding of basic statistical concepts, allowing ICT to support deeper data analysis and exploration of more complex statistics.

However, the effect size at the university level tends to be lower than at the secondary level. This may be attributed to several factors:

a. Higher Prior Knowledge: university students often already have a stronger foundation in statistics, so ICT serves more as a support tool rather than a primary factor for understanding new material.

b. Content Complexity: at the university level, statistics content is significantly more complex and requires advanced analysis, meaning ICT may not fully replace deeper conceptual discussion-based learning.

c. Independent Learning Methods: university students are more frequently expected to learn independently, making technology-based interventions less effective than in more structured secondary education.

At the elementary level, the effectiveness of ICT tends to be more limited because students are still developing fundamental concepts in mathematics and statistics. Nevertheless, ICT that incorporates visual elements—such as interactive graphics and educational games—can still have a positive impact, albeit smaller than at higher levels.

Class Size

Based on the analysis, the effectiveness of ICT is higher in small classes (fewer than 30 students). This can be attributed to several factors:

a. More Intensive Interaction: in small classes, teacher–student interaction is more personal and intensive, allowing ICT to be optimized through direct guidance and faster feedback.

b. Higher Focus: students in smaller classes tend to be more focused and actively engaged in technology-based learning without major distractions.

c. Adequate Resource Allocation: small classes allow more equitable distribution of ICT devices, ensuring students have sufficient access to technology.

d. Optimized Collaborative Learning: approaches such as computer-supported collaborative learning (CSCL) are more effective with fewer students, enabling more structured and in-depth analytical discussions.

In contrast, in large classes, the distribution of technology becomes less equitable and personal interaction decreases, which limits the effectiveness of ICT. Teachers also struggle to provide prompt feedback to all students, impacting reflective learning and deep understanding of concepts.

Geographic Location

Based on the meta-analysis, the effect size of ICT use in Indonesia is relatively similar to that in other countries. This indicates that access to technology and the effectiveness of ICT-based learning are not heavily dependent on geographic location, but rather on the quality of technological infrastructure, teacher training, and the instructional methods used. In Indonesia, government initiatives such as the Digital Learning Initiative and the expansion of internet networks to remote areas have helped improve access to technology. Moreover, the increasing adoption of online and hybrid learning formats has narrowed the gap in ICT utilization compared to developed countries.

Implications for Mathematics Education

The findings of this meta-analysis indicate that strategic use of ICT in statistics education can strengthen students' statistical reasoning and critical thinking skills. This carries important implications for educators in designing technology-based, interactive, and collaborative curricula. In addition, educators should consider moderating factors such as education level, class size, and geographic location to maximize the potential of ICT in statistics instruction.

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Limitations and Recommendations

This meta-analytic review acknowledges several limitations that must be kept in mind. Out of hundreds of articles initially screened, only twenty-five met the inclusion rules and supplied the information needed to compute effect sizes. Almost all of those eligible studies came from narrowly defined educational settings, so the findings may not translate well to different classrooms or learning environments. In addition, several reports lacked essential demographic details, such as students socioeconomic background or prior experience with technology, leaving some potentially important variables unexamined. Despite these limitations, this study contributes significant strengths: it systematically synthesizes evidence across multiple contexts, applies rigorous meta-analytic methods, and provides robust effect-size estimates that underscore the positive role of ICT in enhancing statistical reasoning and critical thinking.

A number of promising studies could not be included because they are locked behind paywalls or because their statistical summaries were too incomplete to permit effect-size calculations. Future work should therefore adopt open-reporting practices and, wherever possible, publish in open-access journals so that a broader, more inclusive evidence base can be built for the next wave of meta-analyses.

The practical consequences are clear: educators and policy decision-makers must embed information and communication technology resources into the core structure of curriculum design rather than relegating them to ancillary status. This embedding process must be coupled with deliberate attention to variables such as the number of students per class, the heterogeneity of learners, and the equitable distribution of technological resources. In parallel, forthcoming investigations ought to widen the evidentiary base by adopting practices of open reporting, disseminating findings through open-access channels, and deliberately including a wider array of demographic and contextual factors. By these means, future meta-analytical reviews will be equipped to account for the complete constellation of variables shaping the efficacy of ICT interventions, thereby furnishing more finely calibrated recommendations that can be applied to educational systems across the globe.

CONCLUSIONS

Research demonstrates that information and communication technology ICT consistently strengthens statistical reasoning and critical thinking in classrooms around the world. Similar evidence, collected between 2016 and 2025, indicates that using ICT also raises overall mathematics performance in Indonesia and many other countries. Students learning with technology are still affected by several moderating factors, notably grade level and the size of the class, both of which can shape their reasoning and analytic skills. In contrast, current studies find little support for the idea that students geographic location meaningfully alters their statistical reasoning or critical thinking when instruction is delivered through ICT.

The results present significant rationale for the design of teacher preparation and ongoing professional learning. Successful integration of information and communication technology (ICT) in classrooms hinges on teachers acquiring two complementary dimensions of expertise: first, a command of the operational functions and features of digital tools; and second, a repertoire of pedagogical approaches that mobilize those tools for sustained inquiry, the detection of bias, the appraisal of evidence, and the construction of robust conceptual understandings. Accordingly, professional development curricula ought to interweave advanced technological fluency with a critically reflective pedagogical stance, thereby empowering educators to orchestrate learning experiences that cultivate sophisticated reasoning across disciplinary domains. When teacher training systematically cultivates these interdependent competencies, the leverage that ICT affords for enhancing student learning outcomes may be both magnified and sustained within varied and evolving educational environments.

BIBLIOGRAPHIC REFERENCES

1. Ben-zvi D, Garfield J. The Challenge of Developing Statistical Literacy, Reasoning and Thinking. 1st ed. Dordrecht: Springer Netherlands; 2004.

2. Régnier JC, Kuznetsova E. Teaching of Statistics: Formation of Statistical Reasoning. Procedia - Soc Behav Sci 2014;154:99–103.

3. Kraft V, Hinrichs C. Preparing Students to Solve Real Problems With Statistics. In: Bridging the Gap: Empowering and Educating Today's Learners in Statistics. Proceedings of the Eleventh International Conference on Teaching Statistics. International Association for Statistical Education; 2022.

4. Conway B, Gary Martin W, Strutchens M, Kraska M, Huang H. The Statistical Reasoning Learning Environment: A Comparison of Students' Statistical Reasoning Ability. J Stat Educ 2019;27(3):171–87.

5. Chan SW, Ismail Z. A technology-based statistical reasoning assessment tool in descriptive statistics for secondary school students (Internet). 2014. http://www.geogebra.org/cms/en/

6. Mat Nor Azmay NA, Rosli R, Maat SM, Mahmud MS. Educational Research Trends on Statistical Reasoning and Statistical Thinking: A Systematic Literature Review. Int J Acad Res Progress Educ Dev 2023;12(2).

7. Dwi Susandi A, Sa C, Rahman As A. M6 Learning Model: The framework to design a learning model that improves students’ critical thinking skill. 2020.

8. Bates J, Cheng S, Ferris M, Wang X (Frank). Cultivating Critical Thinking Skills: A Pedagogical Study in a Business Statistics Course. J Stat Data Sci Educ 2025;33(2):166–76.

9. Berthet V. The Impact of Cognitive Biases on Professionals’ Decision-Making: A Review of Four Occupational Areas. Front Psychol 2022;12.

10. Turan U, Fidan Y, Yıldıran C. Critical Thinking as a Qualified Decision Making Tool. J Hist Cult Art Res 2019;8(4):1.

11. Zuryanty Z, Hamimah H, Kenedi AK, Helsa Y. Proceedings of the 3rd Progress in Social Science, Humanities and Education Research Symposium (PSSHERS 2021). In: Proceedings of the 3rd Progress in Social Science, Humanities and Education Research Symposium (PSSHERS 2021). Paris: Atlantis Press SARL; 2023.

12. Ariani Y. ICT-Based or -Assisted Mathematics Learning and Numerical Literacy: A Systematic Review and Meta-Analysis. Int J Inf Educ Technol 2024;14(3):382–97.

13. Zhang A, Sun H, Shi J, Song J. The Impact of ICT Integration on Students’ Statistics Achievement. 2025;

14. Roopa S, Rajesh KMR. How to cite this article: Roopa S ,Rajesh Kanna M.R (2024) Revolutionizing Learning: The Role of ICT in Enhancing Student Engagement and Achievement (Internet). Available from: www.bpasjournals.com

15. Zainil M, Prahmana RCI, Helsa Y, Hendri S. ICT media design for higher grade of elementary school mathematics learning using CS6 program. J Phys Conf Ser 2017;943:012046.

16. Retnawati H, Kartowagiran B, Arlinwibowo J, Sulistyaningsih E. Why are the Mathematics National Examination Items Difficult and What Is Teachers’ Strategy to Overcome It? Int J Instr 2017;10(3):257–76.

17. Suparman, Juandi D, Martadiputra BAP, Badawi A, Susanti N, Yunita. Cultivating secondary school students’ mathematical critical thinking skills using technology-assisted problem-based learning: A meta-analysis. 2022. page 070006.

18. Keputusan P, Sekolah S, Dalam M, Masalah M, Berdasarkan N, Hanik G, et al. AKSIOMA: Jurnal Program Studi Pendidikan Matematika. 2023;12(1):589–99. https://doi.org/10.24127/ajpm.v12i1.6277

19. Makar K, Fielding-Wells J. Teaching Teachers to Teach Statistical Investigations. 2011. page 347–58.

20. Garfield J. The Challenge of Developing Statistical Reasoning. J Stat Educ 2002;10(3).

21. Jones GA, Thornton CA, Langrall CW, Mooney ES, Perry B, Putt IJ. A Framework for Characterizing Children’s Statistical Thinking. Math Think Learn 2000;2(4):269–307.

22. Wild CJ, Pfannkuch M. Statistical Thinking in Empirical Enquiry. Int Stat Rev 1999;67(3):223–48.

23. Balkaya T, Kurt G. Middle school students’ statistical reasoning about distribution in their statistical modeling processes. Stat Educ Res J 2023;22(1):7.

24. Chan SW, Ismail Z. Developing Statistical Reasoning Assessment Instrument for High School Students in Descriptive Statistics. 5th World Conf Educ Sci (Internet) 2014;116(0):4338–43. http://www.sciencedirect.com/science/article/pii/S1877042814009604

25. Wahba F, Ajlouni AO, Abumosa MA. The impact of ChatGPT-based learning statistics on undergraduates’ statistical reasoning and attitudes toward statistics. Eurasia J Math Sci Technol Educ 2024;20(7):em2468.

26. Christopher Brandt W, Lorié W. Measuring Student Success Skills : a Review of the Literature (Internet). 2024. Available from: www.nciea.org

27. Facione PA. Critical Thinking: What It Is and Why It Counts 2020 Update. 2020.

28. Arifin S, Setyosari P, Sa'dijah C, Kuswandi D. The effect of problem based learning by cognitive style on critical thinking skills and student retention. J Technol Sci Educ 2020;10(2):271.

29. Friedman HH, Frankel M, Friedman LW. Teaching Statistics with Scenarios to Foster Critical Thinking. SSRN Electron J 2016;

30. Jones E, Palmer T. A review of group-based methods for teaching statistics in higher education. Teach Math its Appl An Int J IMA 2022;41(1):69–86.

31. Viet L, Triet M, Loc NP, Nguyen N, Ngan T. Effect of GeoGebra-supported 5E learning model on students' understanding of the area of a trapezium: A quasi-experimental study. Math Teach Res J 2024;16(6).

32. Tam KT, Kaur A, Tan Y, Juan D, Gok CX, Bajuri MR. Formulization of Using Technology in Teaching and Learning of Statistics. Creat Educ 2024;15(01):92–106.

33. Helsa Y, Suparman S, Juandi D, Turmudi T, Ghazali MB. A Meta-Analysis of the Utilization of Computer Technology in Enhancing Computational Thinking Skills: Direction for Mathematics Learning. Int J Instr 2023;16(2):735–58.

34. Tawaldi S, Nurlaelah E, Juandi D, Suparman. Is mathematics anxiety related to mathematics learning outcome? A meta-analysis. 2023. page 090044.

35. Cheung ACK, Slavin RE. How Methodological Features Affect Effect Sizes in Education. Educ Res 2016;45(5):283–92.

36. Hattie J. Visible Learning. Routledge; 2008.

37. Çoğaltay N, Karadağ E. Introduction to Meta-Analysis. In: Leadership and Organizational Outcomes. Cham: Springer International Publishing; 2015. page 19–28.

38. Putri AD, Juandi D, Turmudi, Suparman. Blended Learning and Math Achievement: A Meta-Analytic Review Highlighting the Effectiveness and Heterogeneity. Electron J e-Learning 2025;23(1):113–28.

39. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. Int J Surg 2010;8(5):336–41.

40. Haddaway NR, Page MJ, Pritchard CC, McGuinness LA. PRISMA2020 : An R package and Shiny app for producing PRISMA 2020-compliant flow diagrams, with interactivity for optimised digital transparency and Open Synthesis. Campbell Syst Rev 2022;18(2).

41. Harwell M. Growth in the Amount of Literature Reviewed in a Meta-Analysis and Reviewer Resources. Mid-Western Educ Res 2020;32(2).

42. Bernard RM, Borokhovski E, Schmid RF, Tamim RM, Abrami PC. A meta-analysis of blended learning and technology use in higher education: from the general to the applied. J Comput High Educ 2014;26(1):87–122.

43. Nani K La, Bakar MT, Saidi S. Peningkatan Kemampuan Penalaran Statistis Mahasiswa Melalui Pembelajaran Berbasis Proyek Berbantuan ICT. Edukasi 2020;

44. Masni ED, Ralmugiz U, Rukman NK. Peningkatan kemampuan penalaran dan komunikasi statistik mahasiswa melalui pembelajaan statistik inferensial berbasis proyek dengan meninjau gaya kognitif mahasiswa. Pedagog J Pendidik Mat 2020;5(2):12–26.

45. Maknun J. Implementation of Guided Inquiry Learning Model to Improve Understanding Physics Concepts and Critical Thinking Skill of Vocational High School Students. Int Educ Stud 2020;13(6):117.

46. Yusuf Y, Jaenudin A, R NT. Pengaruh penggunaan modul berbantuan program R terhadap kemampuan penalaran statistik. Semin Nas Mat 2016;1(19):453–8.

47. Wulansari T, Putra A, Rusliah N, Habibi M. Pengaruh model pembelajaran berbasis masalah pada materi statistika terhadap kemampuan penalaran statistik siswa. AKSIOMA J Mat dan Pendidik Mat 2019;10(1):35–47.

48. Subaini S, Irvan I, Nasution MD. Pengaruh Model Pembelajaran Berbasis Masalah Terhadap Kemampuan Berpikir Kritis Matematis Siswa. J MathEducation Nusant 2022;5(2):16.

49. Prameswari G, Apriana R, Wahyuni R. Pengaruh Model Inquiry Learning Terhadap Kemampuan Berpikir Kritis Matematis Siswa Pada Materi Fungsi Kuadrat Kelas X Sma Negeri 3 Singkawang. JPMI (Jurnal Pendidik Mat Indones 2018;3(1):35.

50. Mulyanto H, Gunarhadi G, Indriayu M. The Effect of Problem Based Learning Model on Student Mathematics Learning Outcomes Viewed from Critical Thinking Skills. Int J Educ Res Rev 2018;3(2):37–45.

51. Aldila Afriansyah E, Herman T, Turmudi, Afgani Dahlan J. Critical thinking skills in mathematics. J Phys Conf Ser 2021;1778(1):012013.

52. Pujiastuti H, Ayatullah F, Haryadi R. The Influence of Inquiry Learning Model towards Students' Mathematical Critical Thinking Ability. Unnes J Math Educ 2019;8(3):216–23.

53. Martaida T, Bukit N, Ginting EM. The Effect Of Discovery Learning Model On Critical Thinking Ability In Thematic Learning. IOSR J Res Method Educ 2017;7(6):1–8.

54. ARISOY B, AYBEK B. The Effects of Subject-Based Critical Thinking Education in Mathematics on Students' Critical Thinking Skills and Virtues. Eurasian J Educ Res 2021;21(92).

55. Puspita V, Yuhelman N, Rifandi R. Dampak Pendekatan Realistic Mathematics Education Terhadap Keterampilan Berpikir Kritis Pada Siswa Sekolah Dasar. Justek J Sains dan Teknol 2020;1(2):20.

56. Permanawati FI, Agoestanto A, Kurniasih AW. The studentsâ€TM critical thinking ability through problem posing learning model viewed from the studentsâ€TM curiosity. Unnes J Math Educ 2018;7(3):147–55.

57. Fitriani A, Zubaidah S, Susilo H, Al Muhdhar MHI. PBLPOE: A Learning Model to Enhance Students' Critical Thinking Skills and Scientific Attitudes. Int J Instr 2020;13(2):89–106.

58. Muhammad M, Purwanto J. The effect of Double Loop Problem Solving (DLPS) on critical thinking skills and mathematical problem solving abilities. J Phys Conf Ser 2020;1469(1):012172.

59. Pant P, Muddgal A. A Study of Impact of Ict on Critical Thinking of Elementary Level Mathematics Students. Indian J Public Heal Res Dev 2018;9(12):1745.

60. Ibrahim I, Sujadi I, Maarif S, Widodo SA. Increasing Mathematical Critical Thinking Skills Using Advocacy Learning with Mathematical Problem Solving. J Didakt Mat 2021;8(1):1–14.

61. Rahayu S, Isnaeni W, Masturi M. Critical Thinking Skills and Digital Literacy of High School Students in Science Learning Using E-Learning with STEM Vision. J Innov Sci Educ 2022;11(3):347–61.

62. Kevin A. Artuz J, B. Roble D. Developing Students' Critical Thinking Skills in Mathematics Using Online-Process Oriented Guided Inquiry Learning (O-POGIL). Am J Educ Res 2021;9(7):404–9.

63. Chan SW, Ismail Z, Sumintono B, Omar SS, Ramlan R. The effect of Statistical reasoning Learning Environment in Developing Secondary Student's Statistical reasoning. J Eng ang Appl Sci 2016;11(8):1762–7.

64. Zhao G, Sheng H, Wang Y, Cai X, Long T. Generative Artificial Intelligence Amplifies the Role of Critical Thinking Skills and Reduces Reliance on Prior Knowledge While Promoting In-Depth Learning. Educ Sci 2025;15(5):554.

https://doi.org/10.56294/saludcyt20252049 ISSN: 2796-9711

65. Meidinda F, Azhar E, Jusra H. Pengaruh Model Pembelajaran Discovery Learning Terhadap Kemampuan Berpikir Kritis Matematis Siswa Kelas VIII. Semin Nas Pendidik Mat 2018;01:418–29.

66. Sari IP, Siregar TJ. Increasing students' critical thinking ability in mathematics and fighting power through the implementation of an Open-Ended Approach. Int J Trends Math Educ Res (Internet) 2024;7(1):45–51. https://doi.org/10.33122/ijtmer.v7i1.327

67. Sosa GW, Berger DE, Saw AT, Mary JC. Effectiveness of Computer-Assisted Instruction in Statistics. Rev Educ Res 2011;81(1):97–128.

68. Tedla YG, Chen HL. The impacts of computer-supported collaborative learning on students' critical thinking: a meta-analysis. Educ Inf Technol 2025;30(2):1487–516.

69. Camnalbur M, Erdoğan Y. A meta analysis on the effectiveness of computer-assisted instruction: Turkey sample. Kuram ve Uygulamada Egit Bilim 2008;8(2):497–505.

70. Benková M, Bednárová D, Bogdanovská G, Pavlíčková M. Redesign of the Statistics Course to Improve Graduates' Skills. Mathematics 2022;10(15):2569.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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