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Article abstract

Metacognition refers to the capacity to comprehend and manage one's own cognitive processes, enabling the recognition of biases and presumptions that might influence them. Numerous published studies indicate that through metacognition, enhancements in critical-thinking skills allow individuals to query information, assess data, and make more evidence-grounded decisions—a cornerstone of critical and analytical thinking. This study aims to delineate the association between metacognition and critical-thinking skills via a meta-analysis. The data sources encompass articles published on Scopus between 2013 and 2023, identified using the keywords "Metacogni*" AND "Critical Thinking". This meta-analysis included 60 studies from diverse global locations. Employing a random-effects model, the analysis evaluated both effect size and potential publication biases using Jamovi 2.2.5 and OpenMEE software. The outcomes affirm a significant correlation between metacognition and critical-thinking skills, highlighting a robust effect of metacognition on critical-thinking skills, reflected in a significant measure of $r = 0.649$. Thus, increasing metacognitive abilities will improve critical-thinking abilities.

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Can Critical-thinking Skills be Measured by Analyzing Metacognition?

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Abstract

Metacognition refers to the capacity to comprehend and manage one's own cognitive processes, enabling the recognition of biases and presumptions that might influence them. Numerous published studies indicate that through metacognition, enhancements in critical-thinking skills allow individuals to query information, assess data, and make more evidence-grounded decisions—a cornerstone of critical and analytical thinking. This study aims to delineate the association between metacognition and critical-thinking skills via a meta-analysis. The data sources encompass articles published on Scopus between 2013 and 2023, identified using the keywords "*Metacogni**" AND "*Critical Thinking*". This meta-analysis included 60 studies from diverse global locations. Employing a random-effects model, the analysis evaluated both effect size and potential publication biases using Jamovi 2.2.5 and OpenMEE software. The outcomes affirm a significant correlation between metacognition and critical-thinking skills, highlighting a robust effect of metacognition on critical-thinking skills, reflected in a significant measure of $r = 0.649$. Thus, increasing metacognitive abilities will improve critical-thinking abilities.

Introduction

21st-century skills encompass a range of essential attributes crucial for navigating modern life, particularly in academia and prospective professions. Among these, ways of thinking form a fundamental category. This means creativity, innovation, critical thinking, problem-solving, decision-making, and metacognition (Maoulida et al., 2023; Rahman, 2019). Indeed, based on the information provided, metacognition and creative-thinking skills are identified as integral components within the category of ways of thinking, which fall under the umbrella of 21st-century skills.

The development of these critical-thinking skills is crucial in shaping individuals who are not only capable, but also competitive in the future. These elements play a pivotal role in nurturing high-quality individuals equipped with the ability to analyze, problem-solve, and think innovatively, enhancing their capacity to thrive in a competitive environment (Sukarno & Musyafa, 2021). Over the past two decades around the world, critical-thinking skills have become a highly valued employee competency (McMillan et al., 2022) and a major goal of education (Sulaiman, 2018). Utilizing metacognitive strategies and honing this ability has shown a positive correlation with academic performance. Students who employ these approaches tend to achieve better results in their scholastic pursuits, as these skills empower them to effectively comprehend, analyze, and apply knowledge, ultimately enhancing their performance in various academic tasks and assessments (Trigueros et al., 2020). Clearly, critical-thinking skills significantly contribute to the enhancement of students' reasoning abilities. By encouraging the evaluation of information, questioning assumptions, and analyzing evidence, critical thinking cultivates a more robust and logical approach to reasoning. Students proficient in this way are better equipped to make sound judgments, solve complex problems, and articulate their thoughts with clarity, thereby refining their overall reasoning skills (Murtadho, 2021). These findings conclude that metacognition and critical thinking are two things that are important, not only in learning, but are also necessary in the future working world.

Metacognition and critical-thinking skills are closely interconnected. Metacognition involves understanding one's own thinking processes—being aware of how one thinks and learns. Critical thinking, on the other hand, involves analyzing, evaluating, and reasoning about information. Metacognition enables individuals to reflect on their thinking, recognize biases, and monitor their understanding of a subject. These self-awareness and monitoring processes significantly contribute to the development of critical-thinking skills. In turn, this type of thinking encourages metacognitive practices, by prompting individuals to assess the quality of their thinking, consider alternative viewpoints, and refine their cognitive strategies. Ultimately, these two skill sets complement and reinforce each other, as metacognition aids in optimizing and improving critical-thinking abilities, while critical thinking, in turn, promotes a deeper metacognitive awareness. Metacognition is also needed in critical thinking (Sannathimmappa et al., 2022). One discovery suggested that emphasizing the enhancement of metacognitive skills has the potential to establish habits that reduce biases in students. These habits are expected to enhance students' capacity for critical thinking (Maynes, 2015). However, there are findings that metacognition is negatively correlated with critical-thinking skills (Chang et al., 2021). The varying results regarding the correlation between these two abilities necessitate a comprehensive examination of the existing literature. Presently, there is a lack of studies that systematically consolidate the link between metacognition and critical-thinking skills. This meta-analysis aims to address this gap, by endeavouring to provide a consolidated understanding of their relationship.

A meta-analysis is a methodical and numerical investigation that utilizes pre-existing studies (secondary data) to arrive at precise conclusions (Chamdani et al., 2022). Based on the information provided, it can be inferred that both metacognition and critical-thinking skills hold significance in learning and future professional contexts. The interconnected nature of these skills underscores their importance. To comprehensively understand the relationship between metacognition and critical thinking on a global scale, a meta-analysis is essential. This study aims to be the inaugural meta-analysis exploring the universality of this relationship, incorporating participants from diverse countries and academic levels. Its objective is to empirically establish and quantify the impact of the relationship between metacognition and critical-thinking skills through a quantitative meta-analysis methodology.

Method

This research employs a correlation meta-analysis approach, determining the effect size using a random-effect model. In other words, meta-analysis can be seen as an examination of multiple studies. In the realm of research, it involves analyzing numerous findings related to similar issues, aiming to draw statistical conclusions that consolidate and compare previously gathered data (Kriswanto et al., 2021).

Literature search and literature inclusion criteria

The studies in this meta-analysis were searched electronically through the Scopus database. The search was conducted using search within *article title*, *abstract*, *keyword* with search documents "*metacogni**" AND "*critical thinking*" with document types of articles and proceedings. The gathered literature underwent screening based on specific criteria, primarily, inclusion, which was based on studies that were published in peer-reviewed journals or conference proceedings. Studies in the form of theses, dissertations, chapter books, and reports were excluded. Secondly, studies had to be written in English. Those that did not have full text in English were excluded. Thirdly, the studies had to have been published between 2013 and 2023. Studies prior to 2013 were excluded.

With these search keywords and inclusion criteria, 168 open access articles were found. Furthermore, the articles that had been obtained were filtered based on the criteria for which meta-correlation analysis must report r and N . There were 24 articles that met these criteria (Figure1). From these 24 articles, 60 studies were obtained to be analyzed. The process of sourcing research studies extends to the phase of acquiring those that align with, and are utilized in, the meta-analysis, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) reporting guidelines (Moher et al., 2009; Ridwan et al., 2023).

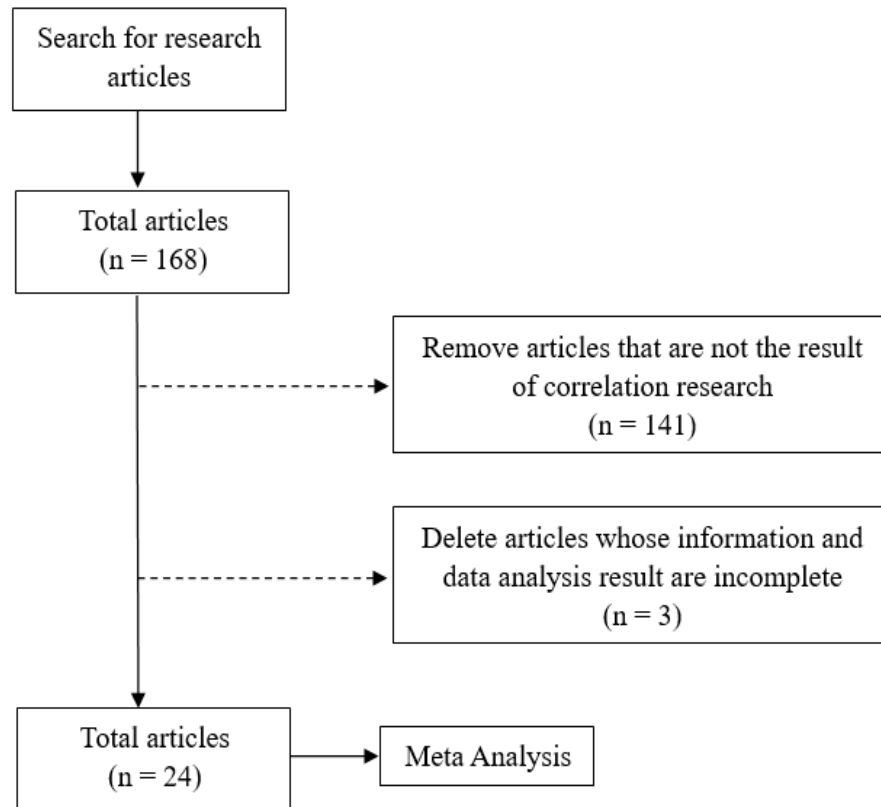


Figure 1. PRISMA flow diagram of literature search.

In more detail, the data obtained can be seen in Table 1.

Table 1. Data collection

| No | Study Name | ID | <i>r</i> | <i>N</i> | Moderator Variable | | |
|----|---------------------------------|----------|----------|----------|--------------------|----------|--------------------|
| | | | | | Participant | Location | Instrument type |
| 1 | (Lehmann, 2022) | Study 1 | 0.260 | 103 | College | Non-Asia | Standardized Scale |
| 2 | (Popova et al., 2022) | Study 2 | 0.350 | 147 | Junior High School | Asia | Custom Scale |
| 3 | (Fernandez-Ortega et al., 2022) | Study 3 | 0.460 | 2439 | Senior High School | Non-Asia | Standardized Scale |
| 4 | | Study 4 | 0.100 | 36 | Junior High School | Asia | Standardized Scale |
| 5 | | Study 5 | 0.200 | 41 | Junior High School | Asia | Standardized Scale |
| 6 | (Kurt & Sezek, 2022) | Study 6 | 0.530 | 37 | Junior High School | Asia | Standardized Scale |
| 7 | | Study 7 | 0.070 | 39 | Junior High School | Asia | Standardized Scale |
| 8 | | Study 8 | 0.670 | 32 | Junior High School | Asia | Standardized Scale |
| 9 | | Study 9 | 0.460 | 185 | Junior High School | Asia | Standardized Scale |
| 10 | (Boran & Karakuş, 2022) | Study 10 | 0.730 | 502 | Junior High School | Asia | Standardized Scale |
| 11 | | Study 11 | 0.435 | 3000 | College | Asia | Standardized Scale |
| 12 | (Jin & Ji, 2021) | Study 12 | 0.444 | 3000 | College | Asia | Standardized Scale |
| 13 | | Study 13 | 0.417 | 3000 | College | Asia | Standardized Scale |
| 14 | | Study 14 | 0.441 | 3000 | College | Asia | Standardized Scale |

| | | | | | | | |
|----|--------------------------------|----------|-------|------|--------------------|----------|--------------------|
| 15 | | Study 15 | 0.461 | 3000 | College | Asia | Standardized Scale |
| 16 | | Study 16 | 0.756 | 33 | Senior High School | Asia | Custom Scale |
| 17 | (Usman et al., 2021) | Study 17 | 0.852 | 33 | Senior High School | Asia | Custom Scale |
| 18 | | Study 18 | 0.723 | 37 | Senior High School | Asia | Custom Scale |
| 19 | | Study 19 | 0.845 | 137 | Elementary School | Asia | Custom Scale |
| 20 | (Tuaputty et al., 2021) | Study 20 | 0.720 | 137 | Elementary School | Asia | Custom Scale |
| 21 | | Study 21 | 0.590 | 450 | College | Non-Asia | Standardized Scale |
| 22 | (Limone et al., 2020) | Study 22 | 0.593 | 230 | College | Non-Asia | Standardized Scale |
| 23 | | Study 23 | 0.591 | 220 | College | Non-Asia | Standardized Scale |
| 24 | (Son, 2020) | Study 24 | 0.629 | 78 | College | Asia | Custom Scale |
| 25 | | Study 25 | 0.905 | 109 | College | Asia | Standardized Scale |
| 26 | | Study 26 | 0.626 | 109 | College | Asia | Standardized Scale |
| 27 | (Amin et al., 2020) | Study 27 | 0.949 | 109 | College | Asia | Standardized Scale |
| 28 | | Study 28 | 0.828 | 109 | College | Asia | Standardized Scale |
| 29 | | Study 29 | 0.790 | 468 | College | Asia | Custom Scale |
| 30 | | Study 30 | 0.770 | 468 | College | Asia | Custom Scale |
| 31 | (Guvén & Cakir, 2019) | Study 31 | 0.590 | 468 | College | Asia | Custom Scale |
| 32 | | Study 32 | 0.480 | 468 | College | Asia | Custom Scale |
| 33 | | Study 33 | 0.190 | 21 | Elementary School | Asia | Custom Scale |
| 34 | (Leasa, 2018) | Study 34 | 0.300 | 25 | Elementary School | Asia | Custom Scale |
| 35 | | Study 35 | 0.740 | 23 | Elementary School | Asia | Custom Scale |
| 36 | (Ghasemi & Dowlatabadi, 2018) | Study 36 | 0.770 | 190 | College | Asia | Standardized Scale |
| 37 | | Study 37 | 0.209 | 111 | College | Non-Asia | Standardized Scale |
| 38 | | Study 38 | 0.122 | 111 | College | Non-Asia | Standardized Scale |
| 39 | | Study 39 | 0.063 | 111 | College | Non-Asia | Standardized Scale |
| 40 | (Marquès Puig et al., 2022) | Study 40 | 0.372 | 111 | College | Non-Asia | Standardized Scale |
| 41 | | Study 41 | 0.229 | 111 | College | Non-Asia | Standardized Scale |
| 42 | | Study 42 | 0.140 | 111 | College | Non-Asia | Standardized Scale |
| 43 | | Study 43 | 0.512 | 52 | College | Asia | Standardized Scale |
| 44 | (Sadeghi et al., 2014) | Study 44 | 0.533 | 50 | College | Asia | Standardized Scale |
| 45 | | Study 45 | 0.520 | 664 | College | Asia | Standardized Scale |
| 46 | | Study 46 | 0.575 | 664 | College | Asia | Standardized Scale |
| 47 | | Study 47 | 0.592 | 664 | College | Asia | Standardized Scale |
| 48 | (Teng & Yue, 2023) | Study 48 | 0.586 | 664 | College | Asia | Standardized Scale |
| 49 | | Study 49 | 0.519 | 664 | College | Asia | Standardized Scale |
| 50 | | Study 50 | 0.526 | 664 | College | Asia | Standardized Scale |
| 51 | (Karaoğlu-Yılmaz et al., 2019) | Study 51 | 0.345 | 244 | College | Asia | Standardized Scale |
| 52 | | Study 52 | 0.600 | 390 | College | Asia | Custom Scale |
| 53 | | Study 53 | 0.580 | 390 | College | Asia | Custom Scale |
| 54 | (Arslan, 2015) | Study 54 | 0.640 | 390 | College | Asia | Custom Scale |
| 55 | | Study 55 | 0.710 | 390 | College | Asia | Custom Scale |
| 56 | (Altay & Saracalo, 2017) | Study 56 | 0.502 | 608 | College | Asia | Custom Scale |
| 57 | (Cakici, 2018) | Study 57 | 0.731 | 218 | College | Asia | Standardized Scale |

| | | | | | | | |
|----|-----------------------------|----------|-------|-----|--------------------|------|--------------|
| 58 | (Kozikoğlu, 2019) | Study 58 | 0.617 | 229 | College | Asia | Custom Scale |
| 59 | (Can, 2021) | Study 59 | 0.542 | 191 | College | Asia | Custom Scale |
| 60 | (Diella & Ardiansyah, 2017) | Study 60 | 0.540 | 100 | Senior High School | Asia | Custom Scale |

Data analysis

Effect size. The data was summarized utilizing various tools, including Microsoft Excel, Jamovi 2.2.5, and OpenMEE software. These programs were employed to ascertain the effect size for individual studies, as well as for the overall and aggregate effect sizes. An overview of the data analysis process is depicted in Figure 2.

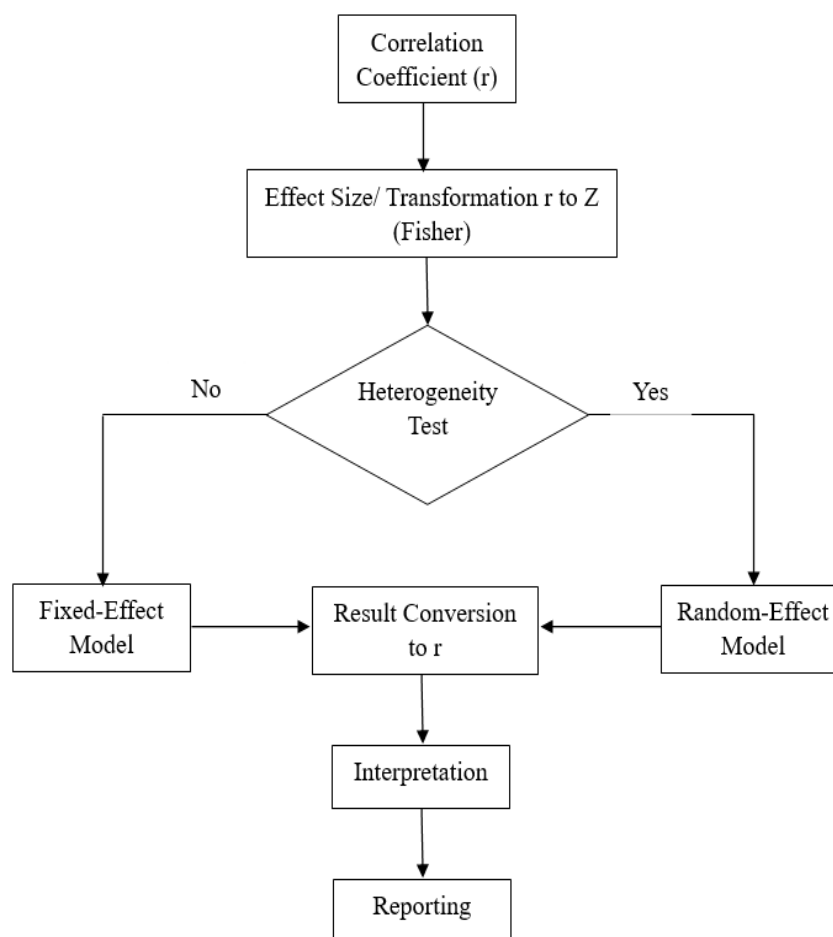


Figure 2. Schematic of correlation meta-analysis.

Cohen's effect size criteria, as outlined by Chamdani et al., (2022) in Table 2, classifies effect sizes according to values ranging from 0 to 1.

Table 1. Cohen's effect size criteria.

| Value | Criteria |
|-------|----------|
|-------|----------|

| | |
|------|--------------------|
| <0.1 | Weak effect |
| <0.3 | Modest effect |
| <0.5 | Moderate effect |
| <0.8 | Strong effect |
| ≥0.8 | Very strong effect |

Evaluation of publication bias. This meta-analysis study used two approaches to explore publication bias, namely funnel plot and fail-safe N. Funnel plot was used to clearly present all effect sizes, and if the pattern formed was symmetrical, it indicated that there was no publication bias (Card, 2011). Fail-safe N was used to estimate the number of studies with insignificant results (unpublished data) needed, so that the average effect size became statistically insignificant (Rosenthal, 1979).

Findings and Discussion

Findings

Effect size. This study aimed to determine the correlation between metacognitive ability and critical-thinking skills. Based on the research of 60 studies, the data obtained are shown in Table 3.

Table 3. Data tabulation of the random-effects model.

| No. | Study Name | <i>r</i> | <i>N</i> | <i>Z</i> | <i>Vz</i> | <i>Sez</i> | No. | Study Name | <i>R</i> | <i>N</i> | <i>z</i> | <i>Vz</i> | <i>Sez</i> |
|-----|------------|----------|----------|----------|-----------|------------|-----|------------|----------|----------|----------|-----------|------------|
| 1 | Study 1 | 0.260 | 103 | 0.266 | 0.010 | 0.100 | 31 | Study 31 | 0.590 | 468 | 0.678 | 0.002 | 0.046 |
| 2 | Study 2 | 0.350 | 147 | 0.365 | 0.007 | 0.083 | 32 | Study 32 | 0.480 | 468 | 0.523 | 0.002 | 0.046 |
| 3 | Study 3 | 0.460 | 2439 | 0.497 | 0.000 | 0.020 | 33 | Study 33 | 0.190 | 21 | 0.192 | 0.056 | 0.236 |
| 4 | Study 4 | 0.100 | 36 | 0.100 | 0.030 | 0.174 | 34 | Study 34 | 0.300 | 25 | 0.310 | 0.045 | 0.213 |
| 5 | Study 5 | 0.200 | 41 | 0.203 | 0.026 | 0.162 | 35 | Study 35 | 0.740 | 23 | 0.950 | 0.050 | 0.224 |
| 6 | Study 6 | 0.530 | 37 | 0.590 | 0.029 | 0.171 | 36 | Study 36 | 0.770 | 190 | 1.020 | 0.005 | 0.073 |
| 7 | Study 7 | 0.070 | 39 | 0.070 | 0.028 | 0.167 | 37 | Study 37 | 0.209 | 111 | 0.212 | 0.009 | 0.096 |
| 8 | Study 8 | 0.670 | 32 | 0.811 | 0.034 | 0.186 | 38 | Study 38 | 0.122 | 111 | 0.123 | 0.009 | 0.096 |
| 9 | Study 9 | 0.460 | 185 | 0.497 | 0.005 | 0.074 | 39 | Study 39 | 0.063 | 111 | 0.063 | 0.009 | 0.096 |
| 10 | Study 10 | 0.730 | 502 | 0.929 | 0.002 | 0.045 | 40 | Study 40 | 0.372 | 111 | 0.391 | 0.009 | 0.096 |
| 11 | Study 11 | 0.435 | 3000 | 0.466 | 0.000 | 0.018 | 41 | Study 41 | 0.229 | 111 | 0.233 | 0.009 | 0.096 |
| 12 | Study 12 | 0.444 | 3000 | 0.477 | 0.000 | 0.018 | 42 | Study 42 | 0.140 | 111 | 0.141 | 0.009 | 0.096 |
| 13 | Study 13 | 0.417 | 3000 | 0.444 | 0.000 | 0.018 | 43 | Study 43 | 0.512 | 52 | 0.565 | 0.020 | 0.143 |
| 14 | Study 14 | 0.441 | 3000 | 0.473 | 0.000 | 0.018 | 44 | Study 44 | 0.533 | 50 | 0.594 | 0.021 | 0.146 |
| 15 | Study 15 | 0.461 | 3000 | 0.499 | 0.000 | 0.018 | 45 | Study 45 | 0.520 | 664 | 0.576 | 0.002 | 0.039 |
| 16 | Study 16 | 0.756 | 33 | 0.987 | 0.033 | 0.183 | 46 | Study 46 | 0.575 | 664 | 0.655 | 0.002 | 0.039 |
| 17 | Study 17 | 0.852 | 33 | 1.263 | 0.033 | 0.183 | 47 | Study 47 | 0.592 | 664 | 0.681 | 0.002 | 0.039 |
| 18 | Study 18 | 0.723 | 37 | 0.914 | 0.029 | 0.171 | 48 | Study 48 | 0.586 | 664 | 0.672 | 0.002 | 0.039 |
| 19 | Study 19 | 0.845 | 137 | 1.238 | 0.007 | 0.086 | 49 | Study 49 | 0.519 | 664 | 0.575 | 0.002 | 0.039 |
| 20 | Study 20 | 0.720 | 137 | 0.908 | 0.007 | 0.086 | 50 | Study 50 | 0.526 | 664 | 0.585 | 0.002 | 0.039 |
| 21 | Study 21 | 0.590 | 450 | 0.678 | 0.002 | 0.047 | 51 | Study 51 | 0.345 | 244 | 0.360 | 0.004 | 0.064 |

| | | | | | | | | | | | | | |
|----|----------|-------|-----|-------|-------|-------|----|----------|-------|-----|-------|-------|-------|
| 22 | Study 22 | 0.593 | 230 | 0.682 | 0.004 | 0.066 | 52 | Study 52 | 0.600 | 390 | 0.693 | 0.003 | 0.051 |
| 23 | Study 23 | 0.591 | 220 | 0.679 | 0.005 | 0.068 | 53 | Study 53 | 0.580 | 390 | 0.662 | 0.003 | 0.051 |
| 24 | Study 24 | 0.629 | 78 | 0.740 | 0.013 | 0.115 | 54 | Study 54 | 0.640 | 390 | 0.758 | 0.003 | 0.051 |
| 25 | Study 25 | 0.905 | 109 | 1.499 | 0.009 | 0.097 | 55 | Study 55 | 0.710 | 390 | 0.887 | 0.003 | 0.051 |
| 26 | Study 26 | 0.626 | 109 | 0.735 | 0.009 | 0.097 | 56 | Study 56 | 0.502 | 608 | 0.552 | 0.002 | 0.041 |
| 27 | Study 27 | 0.949 | 109 | 1.822 | 0.009 | 0.097 | 57 | Study 57 | 0.731 | 218 | 0.931 | 0.005 | 0.068 |
| 28 | Study 28 | 0.828 | 109 | 1.182 | 0.009 | 0.097 | 58 | Study 58 | 0.617 | 229 | 0.720 | 0.004 | 0.067 |
| 29 | Study 29 | 0.790 | 468 | 1.071 | 0.002 | 0.046 | 59 | Study 59 | 0.542 | 191 | 0.607 | 0.005 | 0.073 |
| 30 | Study 30 | 0.770 | 468 | 1.020 | 0.002 | 0.046 | 60 | Study 60 | 0.540 | 100 | 0.604 | 0.010 | 0.102 |

Before determining the summary effect (aggregate effect size), the heterogeneity test was first carried out. Table 4 displays the outcomes of this test.

Table 4. Heterogeneity test.

| Tau | Tau² | I² | H² | Df | Q | P |
|------------|------------------------|----------------------|----------------------|-----------|----------|----------|
| 0.325 | 0.1058 (SE= 0.0212) | 98.07% | 51.827 | 59 | 1163.959 | <0.001 |

These test findings indicated significant heterogeneity among the 60 effect sizes from the analyzed studies, evidenced by $Q = 1163.959$ with $p < 0.001$, τ^2 or $\tau > 0$, and $I^2 = 98.07\%$ —nearly approaching 100%. Due to this heterogeneity, the Random-Effect Model was employed to establish the aggregate effect size. Table 5 showcases the results detailing the aggregate effect size.

Table 5. Random-effect model (k= 60).

| | Estimate | Se | Z | P | CI Lower Bound | CI Upper Bound |
|-----------|-----------------|-----------|----------|----------|-----------------------|-----------------------|
| Intercept | 0.649 | 0.0439 | 14.7 | <0.001 | 0.593 | 0.704 |

The analysis conducted via the random effect model revealed a noteworthy positive correlation between metacognitive ability and students' critical-thinking skills ($z = 14.7$; 95% CI [0.593; 0.704]). With a p-value of <0.001, the study's null hypothesis (H_0) is convincingly rejected. Consequently, it can be inferred that a significant relationship exists between metacognitive ability and critical-thinking skills, falling within the strong category ($r = 0.649$).

Additionally, the findings were visually presented using a forest plot, a helpful graphical method. This plot illustrated the estimated combined effect through plotted points at specific intervals, which aided in clearer comparisons between the studies. Notably, the effect sizes within the analyzed literature ranged from -0.27 to 2.01 according to the forest plot diagram.

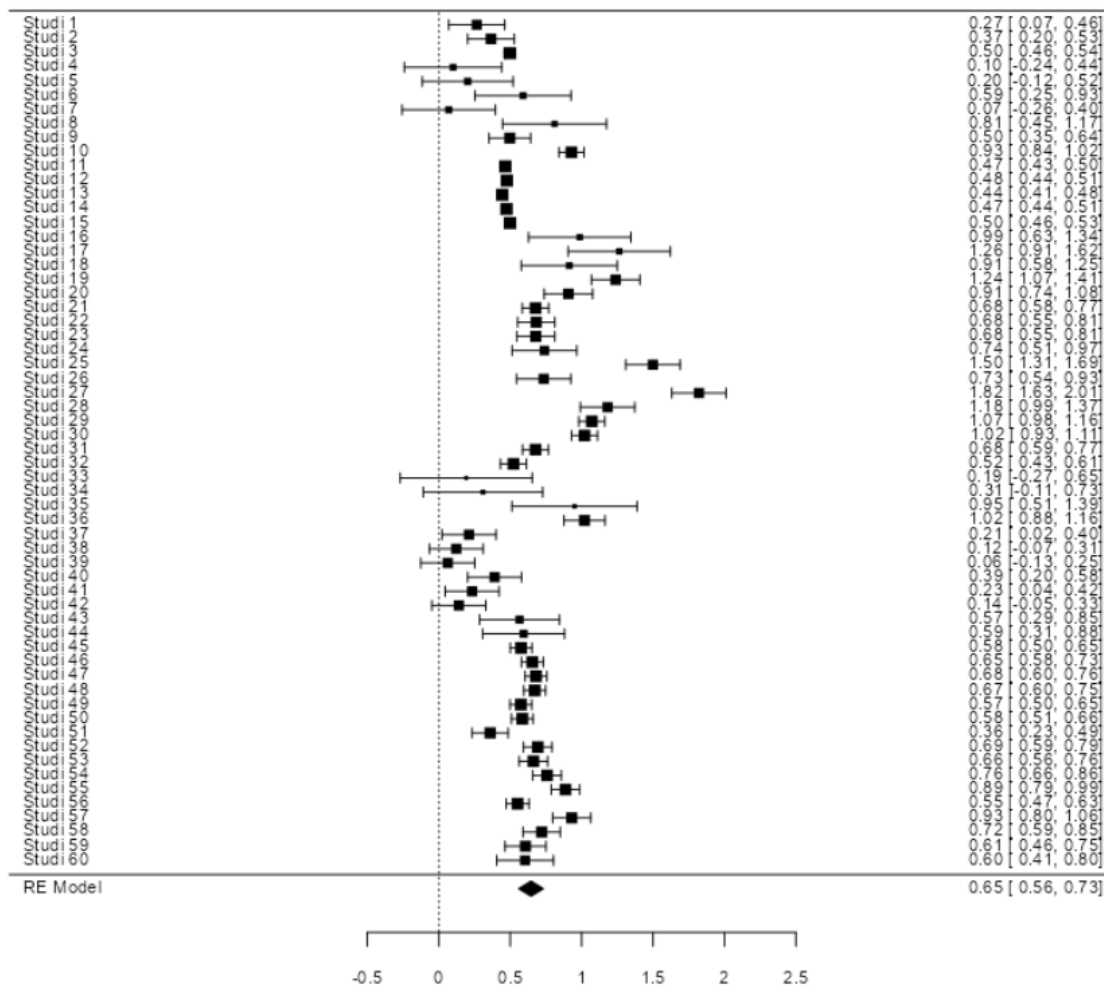


Figure 3. The forest plot analysis of the relationship between metacognition and critical-thinking skills.

Table 6 delineates the distribution of the 60 studies across various moderator variables, categorizing each study according to these specific classifications.

Table 6. Moderator variable.

| Moderator variable | Category | n (%) |
|--------------------|--------------------|------------|
| Publication type | Proceeding | 3 (5) |
| | Journal | 57 (95) |
| Location | Asia | 49 (81.67) |
| | Non-Asia | 11 (18.33) |
| Academic level | Elementary School | 5 (8.33) |
| | Junior High School | 8 (13.33) |
| | Senior High School | 5 (8.33) |
| | College | 42 (70) |
| Instrument Type | Custom Scale | 22 (36.67) |
| | Standardized Scale | 38 (63.33) |

Table 7 illustrates the outcomes derived from the aggregate effect size analysis concerning the moderator variable, "Academic level." This table presents the synthesized results pertaining to how different academic levels influenced the aggregate effect size.

Table 7. Aggregate effect size of academic level.

| Studies | Estimate | Lower bound | Upper bound | Std. error | p-Val |
|-----------------------------|----------|-------------|-------------|------------|---------|
| Subgroup College | 0.654 | 0.592 | 0.717 | 0.032 | < 0.001 |
| Subgroup Senior High School | 0.893 | 0.491 | 1.295 | 0.205 | < 0.001 |
| Subgroup Junior High School | 0.380 | 0.218 | 0.542 | 0.083 | < 0.001 |
| Subgroup Elementary School | 0.761 | 0.417 | 1.105 | 0.176 | < 0.001 |
| Overall | 0.649 | 0.593 | 0.704 | 0.028 | < 0.001 |

The presented results indicate a noteworthy correlation between metacognitive ability and critical-thinking skills across each academic level, as evidenced by p-values consistently below 0.001, or smaller than 0.05 for each academic tier. Additionally, the table demonstrates a strong correlation between metacognitive ability and critical-thinking skills at the college, senior-high-school, and elementary-school academic levels. At the junior-high-school level, the correlation between metacognition and critical-thinking skills registers as moderate.

The results of the aggregate effect size analysis using Asian and non-Asian location moderator variables can be seen in Table 8.

Table 8. Aggregate effect size location moderator variables.

| Studies | Estimate | Lower bound | Upper bound | Std. error | p-Val |
|-------------------|----------|-------------|-------------|------------|---------|
| Subgroup Non Asia | 0.375 | 0.253 | 0.497 | 0.062 | < 0.001 |
| Subgroup Asia | 0.715 | 0.652 | 0.778 | 0.032 | < 0.001 |
| Overall | 0.649 | 0.593 | 0.704 | 0.028 | < 0.001 |

The presented results highlight a significant correlation between metacognitive ability and critical-thinking skills within both Asian and Non-Asian subgroups, evident from p-values consistently below 0.001, or smaller than 0.05 for each location. Moreover, the table illustrates a strong correlation between metacognition and critical-thinking skills in the Asian subgroup, while the correlation in the non-Asian subgroup is moderate.

Table 9 presents the outcomes obtained from the aggregate effect size analysis, based on the moderator variable "instrument type," distinguishing between Standardized Scale and Custom Scale. This table encapsulates the synthesized findings regarding how different types of instruments affected the aggregate effect size concerning metacognitive ability and critical-thinking skills.

Table 9. Aggregate effect size moderator variable of instrument type.

| Studies | Estimate | Lower bound | Upper bound | Std. error | p-Val |
|-----------------------------|----------|-------------|-------------|------------|---------|
| Subgroup Standardized Scale | 0.589 | 0.527 | 0.650 | 0.031 | < 0.001 |
| Subgroup Custom Scale | 0.768 | 0.668 | 0.868 | 0.051 | < 0.001 |
| Overall | 0.649 | 0.593 | 0.704 | 0.028 | < 0.001 |

The presented results indicate a significant correlation between metacognitive ability and critical-thinking skills within both the Standardized Scale and Custom Scale subgroups, as evidenced by

p-values below 0.001, or smaller than 0.05 for each instrument type. Additionally, the table demonstrates a strong correlation between metacognitive ability and critical-thinking skills in both the Standardized Scale and Custom Scale subgroups.

For the analysis based on the moderator variable, "publication type," involving journals and proceedings, the results can be observed in Table 10, which showcases the outcomes of the aggregate effect size analysis concerning how different publication types impact the relationship between metacognitive ability and critical-thinking skills.

Table 10. Aggregate effect size moderator variable of publication type.

| Studies | Estimate | Lower bound | Upper bound | Std. error | p-Val |
|---------------------|----------|-------------|-------------|------------|---------|
| Subgroup Journal | 0.653 | 0.597 | 0.710 | 0.029 | < 0.001 |
| Subgroup Proceeding | 0.486 | 0.027 | 0.944 | 0.234 | 0.038 |
| Overall | 0.649 | 0.593 | 0.704 | 0.028 | < 0.001 |

The outcomes presented above highlight a significant correlation between metacognition and critical-thinking skills within both the journal and proceedings subgroups, supported by p-values smaller than 0.05 for each subgroup. Moreover, the table illustrates a strong correlation between metacognitive ability and critical-thinking skills in the journal subgroup, while the correlation in the proceeding's subgroup registers as moderate.

Evaluation of publication bias. The funnel plot of the 60 studies indicated that the effect size plot spreads from negative to positive values (see Figure 4). The funnel plot also shows that the studies have varying standard errors. A symmetrical funnel plot in a linear regression test suggests that among the 60 studies analyzed, there was no significant asymmetry. This symmetry indicates that publication bias, which might skew results by favouring certain types of studies, does not seem to strongly influence the overall findings of this analysis.

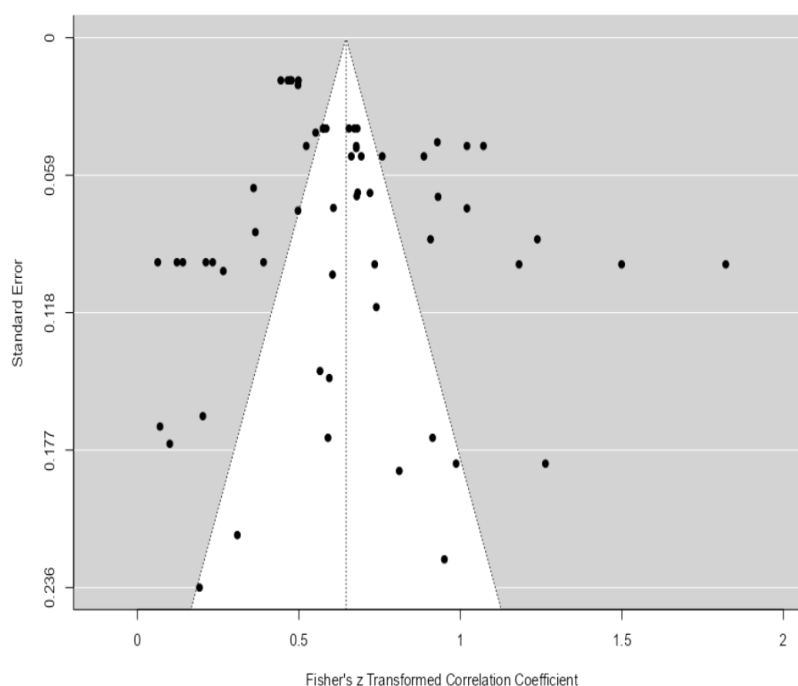


Figure 4. Funnel plot of metacognition effect size on critical-thinking skills.

The fail-safe N calculation, utilizing the Rosenthal approach, resulted in a value of 151125, with an observed significance level of <0.001 , and a target significance level of 0.05. According to Rothstein's guideline (2008), a fail-safe N value exceeding $5K + 10$ (where K represents the number of individual studies) suggests the absence of publication bias in the meta-analysis. In this study, with $K = 60$, the computed threshold is 310 ($5(60) + 10 = 310$). Comparing this threshold to the fail-safe N value of 151125, it is reasonable to conclude that there is not a significant publication bias problem in this analysis. Meanwhile, according to Begg and Mazumdar, a value of 0.025, which is smaller than the confidence interval of 0.783, indicated that there is no publication bias in this research (Begg & Mazumdar, 1994). Similarly, according to Egger, a value smaller than the confidence interval also implies the absence of publication bias (Lin & Chu, 2018). Additionally, Begg and Mazumdar's Rank Correlation and Egger's Regression both propose that there is no publication bias, if the funnel plot is symmetrical.

Tabel 11. Publication bias assessment.

| Test name | value | P |
|------------------------------------|--------|---------|
| Fail-Safe N | 151125 | $<.001$ |
| Begg and Mazumdar Rank Correlation | 0.025 | 0.783 |
| Egger's Regression | -0.286 | 0.775 |

Discussion

According to the data analysis outcomes, the research sample indicates a meaningful positive correlation between metacognition and critical thinking skills (p-value <0.05). As students demonstrate greater proficiency in utilizing metacognitive knowledge, orchestrating and overseeing their learning processes, rectifying errors, and evaluating their learning experiences, their critical thinking skills tend to improve (Maoulida et al., 2023b; Pamungkas et al., 2019; Sukarno & Musyafa, 2021).

Additionally, the effect size analysis reveals that the correlation between metacognition and critical thinking skills falls within the strong category according to Cohen's criteria ($r = 0.649$). This substantial correlation underscores the robust relationship between metacognition and the development of critical-thinking abilities. Practicing students' metacognition skills is considered effective in improving critical-thinking skills. Therefore, teachers' efforts in improving students' critical-thinking skills should not only focus on the use of learning models and teaching materials. Indeed, while highlighting the significance of metacognition skills, it is equally crucial to emphasize and consider students' foundational abilities. These fundamental skills form the bedrock upon which higher-order cognitive functions, like metacognition and critical thinking, are built. Therefore, acknowledging and nurturing these foundational abilities alongside metacognition skills is essential for a comprehensive approach to student development (Nusantari et al., 2021). The results obtained from this meta-analysis align with previous studies examining the correlation between metacognition ability and critical thinking skills. This consistency across multiple studies reinforces the understanding of the strong relationship between these two constructs, emphasizing the reliability and robustness of their association in academic contexts (Guyen & Cakir, 2019; Kozikoğlu, 2019; Son, 2020).

Metacognition, indeed, holds a crucial role in fostering the development of critical thinking. It empowers individuals to become conscious of their thinking processes, enabling them to enhance these processes for better knowledge acquisition. Critical thinking thrives on well-operating metacognitive mechanisms that facilitate awareness of the cognitive processes, actions, and emotions involved. This awareness allows individuals to recognize inadequacies, understand areas for improvement, and subsequently refine their thinking strategies to achieve better outcomes (Rivas et al., 2022).

Furthermore, the moderator variables were analyzed. When viewed from the academic level, metacognition has a significant relationship with critical-thinking skills at each academic level. This is evidenced by the p-value at each academic level (p-value <0.05). The analysis results show that the relationship between metacognition and critical thinking skills is at a strong level at the college and elementary school levels. This result is consistent with several studies on metacognition and critical thinking skills (Amin et al., 2020; Guven & Cakir, 2019; Son, 2020; Tuaputty et al., 2021). This finding contradicts research (Leasa, 2018; Lehmann, 2022; Marquès Puig et al., 2022) which found that the relationship between metacognition ability and critical-thinking skills was at a low level. However, results obtained at the junior-high-school academic level showed that metacognition ability and critical-thinking skills had a weak relationship ($r=0.380$), which is consistent with previous research (Kurt & Sezek, 2022; Popova et al., 2022).

In terms of the type of instrument used, it shows that metacognitive ability and critical-thinking skills have a significant relationship. There is no difference in the relationship between those who use standardized instruments and instruments developed by researchers. These findings are consistent with other findings (Ghasemi & Dowlatabadi, 2018; Guven & Cakir, 2019) which state that metacognition and critical-thinking skills have a significant relationship using standardized instruments and using researcher-developed instruments. Analysis on other moderator variables also shows that metacognition and critical-thinking skills have a significant relationship both from the continent variable (Asian or non-Asian) and the publication type variable (journal or proceedings).

Moreover, when exploring other moderator variables, like continent (Asian or non-Asian) and publication type (journal or proceedings), the analysis affirms a consistent and significant relationship between metacognition and critical-thinking skills across these different categories. This consistency echoes the robustness of the relationship between these constructs, regardless of geographical locations or publication sources

Conclusion and Recommendations

The limitation of this study is the reliance solely on Scopus indexed publications in English, excluding studies published in other languages, potentially impacting the comprehensiveness and inclusivity of the findings, and missing out on valuable insights from studies published in non-English languages. From the presented results and discussions, this research identified the significant relationship between metacognitive ability and critical-thinking skills. The effect size derived from analyzing 60 heterogeneous studies demonstrated a robust and positive correlation. Moreover, the absence of publication bias signified that the reviewed publications accurately represent the actual scenario. The diverse characteristics of these publications specified samples drawn from various scientific fields. It is recommended that future researchers explore whether similar themes are evident within specific academic disciplines, such as mathematics, physics, geography, economics, or other domains, to comprehensively understand the relationship between metacognitive abilities and critical-thinking skills.

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