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The Effectiveness of Collaborative Learning on Critical Thinking, Creative Thinking, and Metacognitive Skill Ability: Meta-Analysis on Biological Learning

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Abstract: This review explores research into the effects of collaborative learning interventions on critical thinking, creative thinking, and metacognitive skill ability on biological learning. The search was conducted from 2000 to 2021. We found 36 critical thinking studies, 18 creative thinking studies, and 14 metacognitive skill studies that met the criteria. The results showed that collaborative learning influences large categories (ES=4.23) on critical thinking, influences large categories (ES= 7.84) on creative thinking, and influences large categories (ES= 8.70) on metacognitive skill. The study's findings show that collaborative learning interventions have the highest impact on metacognitive abilities. Based on these findings, we provide insights for education research and practitioners on collaborative learning interventions that seem to benefit the empowerment of high levels of thinking at various levels of education to be combined with various other interventions in the future. The type of intervention, level of education, materials used, and study quality criteria were included in the study.

Keywords: *Biological learning, collaborative learning, creative thinking, critical thinking, metacognitive skill, meta-analysis.*

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Introduction

The second decade of the 21st century is over. In this phase, the learning process in school is not just about writing and multiple choices tests of the material taught (Kaufman & Sternberg, 2006), The current learning process in schools should have the goal to develop students as individuals who have high levels of thinking skills such as critical thinking (Hunaepi et al., 2020; Muhdhar et al., 2021; Suwono et al., 2019; Wanah et al., 2021; Yennita & Zukmadini, 2021; Yuwentin et al., 2020) creative (Ellianawati et al., 2020; Irawan et al., 2021; G. Kusumawati et al., 2021; R. Kusumawati et al., 2019; Nurhalizah et al., 2020; Wahyu et al., 2016) and metacognitive (Aisyafahmi et al., 2019; Leny et al., 2020; Rahman et al., 2020; Ridlo & Lutfiya, 2017; Siswati & Corebima, 2020; Tumewu et al., 2017).

The school learning process is designed for students to put the knowledge they have into the problems of everyday life so that there will be a clash between knowledge and reality in everyday life (Larson & Miller, 2011; Larson et al., 2010). To solve the problems, students are required to think critically about existing problems (Pascarella et al., 2014; Pascarella & Terenzini, 2005), Solve Problems, and eventually, they will find solutions with their creative thinking skills (Hwang et al., 2007; Paul & Elder, 2019; Villalba, 2017). To think creatively, students need the student's skills to study the extent of knowledge he has, what knowledge he does not already have, and set up a way to acquire knowledge that does not already have is a metacognitive skill (Amin et al., 2020; Flavell, 1979; Greenstein, 2012; Livingston, 1997). The combination of critical thinking, creative thinking, and metacognitive skills will make students successful and survive the challenges of 21st century life (Chalkiadaki, 2018; van Laar et al., 2020; ŽivkoviĿ, 2016).

Critical thinking is one of the skills considered important in students' learning process in the 21st century, which relates to stakeholders, and in everyday family life (Moeti et al., 2016). Critical thinking can also be seen as part of a more general convergent thinking skill that involves the production of one correct answer. Critical thinking generally involves the ability to analyze and identify problems. In other words, to be able to do critical thinking requires the ability to analyze

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arguments and construct thinking so that it can finally solve problems. This critical thinking ability is the foundation for developing higher thinking skills such as creative thinking (Hwang et al., 2007).

Creative thinking skills or divergent thinking skills are thinking skills that can produce answers varied and different from those that have existed before. Creative thinking can enhance talent and talent development as needed in the 21st century (Daud et al., 2012). There are four criteria of creative thinking according to Munandar (2009, 2012) among others: fluency, flexibility, authenticity in thinking, and elaboration or detail in developing ideas. According to Coffman (2012), There are several ways to practice creative thinking skills, namely: through asking questions and inviting students to participate in learning actively; through the exploration of topics and materials with primary/accurate data; and through thinking about new ways to inform new findings.

Metacognitive was defined as thinking about thinking (Greenstein, 2012), conjecture thoughts about his thoughts (Flavell, 1979), the ability to monitor learning development, and reflect on what has been done during the learning process (Livingston, 1997). Metacognitive skill has a very close relationship with a person's thinking ability (Amin et al., 2020). Magno (2010) states that critical thinking is when individuals use thinking skills or strategies to increase the likelihood of obtaining the learning outcomes they want to achieve. Furthermore, Amin and Sukestiyarno (2015) Explaining the essential element of empowering metacognitive skills is to teach students in a small group by presenting activities focused on Discovery and problem solving; the activity aims to reinforce learning and thinking activities.

One of the learnings that became a trend in the 21st century was collaborative learning (Leonard & Leonard, 2001). Collaborative learning is the process of two or more students working together to find a shared solution to an existing group task (Asterhan & Schwarz, 2016; Dillenbourg, 1999; Johnson & Johnson, 2009; MacGregor, 1990; Roschelle, 1992; Smith & MacGregor, 1993; Srinivas, 2011; Sung et al., 2017; van Leeuwen & Janssen, 2019). Johnson and Johnson, (2009) demonstrate five essential elements in collaborative learning as follows: (1) positive interdependence that is felt; (2) sufficient interaction; (3) individual accountability and personal responsibility; and (4) evaluate the group.

Over the past decade, researchers in different regions have tried to implement various collaboratively characterized learning to critical thinking skills (Aiman & Hasyda, 2020; Chusni et al., 2021; Nusantari et al., 2021), creative thinking (Nurhalizah et al., 2020; Zubaidah & Corebima, 2020), and metacognitive skill (Astriani et al., 2020; Listiana et al., 2016) on biology learning at the sharing level of education. Previous research on collaborative learning implementation led to varying outcomes (Cooke & Moyle, 2002; Hwang et al., 2007) this creates anxiety for teachers and stakeholders because they feel confused in determining the learning that will be used to train critical thinking, creative thinking, and metacognitive skills, especially in biological learning. Solving the problem requires a thorough study that can conclude the entire research.

Research that makes it possible to conclude sharing similar research is a research meta-analysis. Meta-analysis is a statistical technique to combine the results of 2 or more similar studies so that the data alloy is obtained quantitatively (Cooper et al., 2019; Retnawati et al., 2018). The meta-analysis offers statistical analysis of a large collection of results from individual studies to create generalizations (Borenstein et al., 2007; Cohen et al., 2000; Cooper et al., 2019; Glass, 2006; Green, 2005; Perry & Hammond, 2002).

The results of previous meta-analyses show that collaborative learning is highly effective and often superior to individual learning in terms of academic achievement (Huang et al., 2013). Several other meta-analyses show that students working in small groups achieve higher learning outcomes than students who do assignments individually (J. Chen et al., 2018; Kyndt et al., 2013; Rohrbeck et al., 2003; Roseth et al., 2008). A recent meta-analysis study examined collaboratively characterized learning in mathematical materials (Rakes et al., 2020; Xie et al., 2020; Yunita et al., 2020), on natural science materials (Hillmayr et al., 2020; Utami & Astawan, 2020). Meanwhile, the study of meta-analysis and session systematic review of learning characterized collaboratively to critical thinking, creative thinking, and metacognitive skills for biological materials has still not been done. Therefore, through this research, we need to synthesize the results of previous individual studies to explore and generalize the effectiveness of collaborative learning to critical thinking, creative thinking, and metacognitive skills in biological learning. Without evidence of meta-analysis results, we would never know the magnitude of the practical effect of using collaborative learning on all these skills on biological learning, which collaborative learning has the most influence on those skills, and at which level of education collaborative learning has the most power of influence. Therefore, this meta-analysis of the influence of collaborative learning on critical thinking, creative thinking, and metacognitive skills on biological learning needs to be done.

Methodology

This meta-analysis method adopts the PRISMA meta-analysis from the Cochrane Handbook for Systematic Review of Intervention (Higgins et al., 2019) as a guideline for conducting meta-analyses and systematic reviews.

Search Strategy

The literature search was conducted using electronic data from Science Direct, ProQuest, Crossref, and Google Scholar. The search was completed from 2000 to August 2021. The search is conducted using two languages, Indonesian and English. The author limits the learning model; learning is characterized collaboratively as five models: PBL, PjBL, Inquiry, Discovery learning, Group Investigation. The process of searching literature is done by applying the keywords of Indonesian and English as follows:

Table 1. Search Keywords from Indonesian and English

Language	Skills	Keywords
Indonesian	Berpikir kritis	"PBL" + "berpikir kritis", "Problem based learning" + "berpikir kritis", "Pembelajaran Berbasis Masalah" + "berpikir kritis", "PjBL" + "berpikir kritis", "Project based learning" + "berpikir kritis", "Pembelajaran Berbasis Proyek" + "berpikir kritis", "Inkuiri" + "berpikir kritis", "Inquiry" + "berpikir kritis", "Group Investigation" + "berpikir kritis", "kelompok investigasi" + "berpikir kritis", discovery" + "berpikir kritis", "penemuan" + "berpikir kritis"
	Berpikir kreatif	"PBL" + "berpikir kreatif", "Problem based learning" + "berpikir kreatif", "Pembelajaran Berbasis Masalah" + "berpikir kreatif", "PjBL" + "berpikir kreatif", "Project based learning" + "berpikir kreatif", "Pembelajaran Berbasis Proyek" + "berpikir kreatif", "Inkuiri" + "berpikir kreatif", "Inquiry" + "berpikir kreatif", "Group Investigation" + "berpikir kreatif", "kelompok investigasi" + "berpikir kreatif", "discovery" + "berpikir kreatif", "penemuan" + "berpikir kreatif"
	Metakognitif	"PBL" + "metakognitif", "Problem based learning" + "metakognitif", "Pembelajaran Berbasis Masalah" + "metakognitif", "PjBL" + "metakognitif", "Project based learning" + "metakognitif", "Pembelajaran Berbasis Proyek" + "metakognitif", "Inkuiri" + "metakognitif", "Inquiry" + "metakognitif", "Group Investigation" + "metakognitif", "kelompok investigasi" + "metakognitif", "discovery" + "metakognitif", "penemuan" + "metakognitif"
English	Critical thinking	"PBL" + "Critical thinking," "Problem-based learning" + "Critical thinking," "PjBL" + "Critical thinking," "Project-based learning" + "Critical thinking," "Inquiry" + "Critical thinking," "Grup Investigation" + "Critical thinking," "Discovery" + "Critical thinking."
	Creative thinking	"PBL" + "Creative thinking," "Problem-based learning" + "Creative thinking," "PjBL" + "Creative thinking," "Project-based learning" + "Creative thinking," "Inquiry" + "Creative thinking," "Grup Investigation" + "Creative thinking," "Discovery" + "Creative thinking."
	"Metacognitive"	"PBL" + "Metacognitive", "Problem based learning" + "Metacognitive", "PjBL" + "Metacognitive", "Project based learning" + "Metacognitive", "Inquiry" + "Metacognitive", "Grup Investigation" + "Metacognitive", "Discovery" + "Metacognitive"

Study Inclusion

Studies qualify for this meta-analysis if they conform to predefined inclusion and exclusion criteria. Studies may be included if (1) the study is focused on learning biological materials; (2) the learning model used is collaboratively characterized learning such as PBL, PjBL, Inquiry, Discovery learning, Group Investigation compared to control classes; (3) the study provides critical thinking, creative thinking and metacognitive skill information measured after the learning process; and (4) studies provide basic statistical information such as sample number, average value, standard deviation or variance in each class of experimentation and control.

Data Extraction

Information is categorized based on author, year, learning model in practical classes, location, level of education, sample number, average value, standard deviation, *effect size.* The critical thinking data that was successfully encoded can be seen in Figure. 1, creative thinking Figure. 2 and metacognitive skill on Figure 3.

Risk of Bias Research

Assessment of the quality of bias risk from qualified studies conducted by the rubric of publication assessment can be from Cochrane (Bryant et al., 2005) Modified tailored assessments for this type of publication on educational research. Assessment indexes are categorized by category: sample determination techniques, including their randomization techniques, sample and instrument measurement, data analysis, data delivery, study reporting, and other biases. Based on information taken from the main study, each domain was rated with the categories "high," "unclear," or "low."

Statistical Analysis

Data from the included study is included in Review Manager 5.4 (RevMan), which is software Cochrane developed for systematic review research and meta-analysis. The process of data analysis is divided into two stages. First, the analysis explores the effect size of individual studies. Second, for continuous results, the combined effect size calculation of the entire study (Starnes et al., 2010). This analysis was created to answer the overall question of whether there is evidence collaborative learning can influence critical thinking, creative thinking, and metacognitive skill (Higgins et al., 2019). In this approach, the standard deviation value is used in conjunction with the number of samples to calculate the weight of each study (Higgins et al., 2019).

Findings / Results

Collaborative Learning of Critical Thinking

A search of critical thinking literature conducted using keywords and data-based that has been determined to produce as many as 2268 related studies. Furthermore, the selection process was carried out to discard duplicated studies, which resulted in 1886 studies that passed duplication selection. A total of 1034 studies were issued because they were not studies that used collaborative learning and were no studies conducted in biology. Furthermore, 852 studies were obtained for a thorough review of the article. The results of the 815 studies were discarded because the study did not compare the experimental class with the control class, and the study did not contain basic statistical information that allowed for a meta-analysis. Finally, a total of 36 studies met the criteria for meta-analysis (Figure1).

A total of 36 studies used 1191 subjects as practical classes and as many as 1184 subjects as control classes in empowering critical thinking. Twenty-five studies using problem-based learning, ten studies using inquiry-based learning, Pjbl sides, and Discovery was learning each as much as one study. While for the control class, as many as 18 studies reported conventional learning, three studies used inquiry, two discovery studies, one cooperative learning study, one 5E learning, and the rest did not mention the specific learning model.

Based on the level of education, as many as seven studies reported interventions at the higher education level, 18 studies at the high school level, ten studies at the junior level, 1 study at the elementary level, and 1 study did not report the level of study. Based on the materials taught, a total of 13 studies used human anatomical and physiological materials, ten studies using ecosystem and environmental materials, four studies using material diversity of living things, one study of cell biology, one study of genetics, one study of microbiology, and five studies did not report the material used (Appendix 1).

The image in appendix 1 presents the effect size calculations and standard errors of each study. The highest effect size value was produced by CRTL 35 study of 4.07, and the most insuring was produced by CRTL study 14 with a value of .02. The highest error standard was produced by CRTL study 19 with a value of 2.12, and the lowest produced by CRTL study 33 with a value of .07. The amount of effect size and standard error values of each study will affect the calculation of the overall meta-analysis.

Figure 2 meta-analysis results show values I^2 = 97%, P<.05, Mean Difference combined 4.23 with 95%Cl combined ranging from 3.53, 4.93. A grade I^2 gives the level of diversity of each study. Based on the value I^2= 97% calculation, this indicates significant heterogeneity. While the combined Mean Difference value indicates how much influence collaborative learning has on overall critical thinking. Based on the calculation of a combined Mean Difference value of 4.23, it means that each collaborative learning treatment will have an effect of 4.23 on critical thinking.

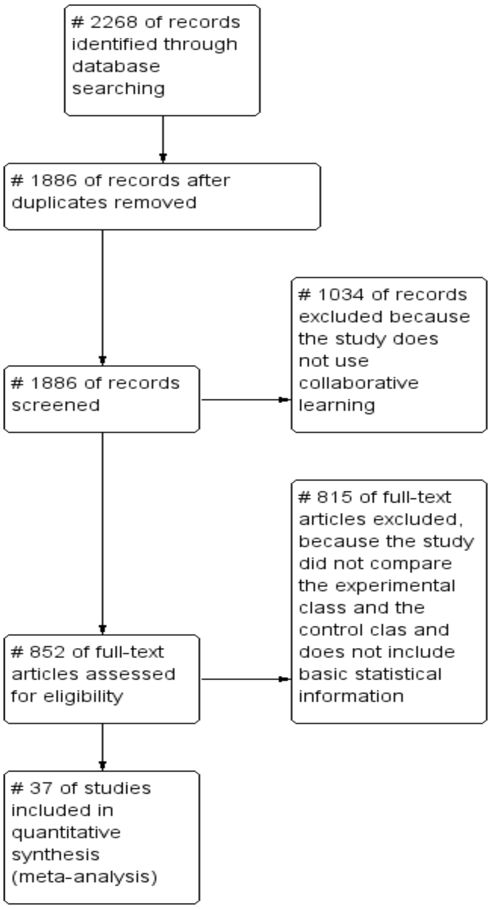

Figure 1. PRISMA Diagram of Critical Thinking

	Experiment			Control				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
CRTL 1	72.25	3.95	30	81	4.33	30	4.3%	-8.75 [-10.85, -6.65]
CRTL 10	73.61	8.2	34	61.62	9.31	32	2.0%	11.99 [7.75, 16.23]
CRTL 11	68.84	4.98	38	75.14	4.67	38	4.2%	-6.30 [-8.47, -4.13]
CRTL 12	72.43	4.57	26	60.41	6.84	24	2.8%	12.02 [8.77, 15.27]
CRTL 13	85.58	78.53	31	83.87	82.99	32	0.0%	1.71 [-38.18, 41.60]
CRTL 14	76.9	10.4	30	65.9	10.2	30	1.4%	11.00 [5.79, 16.21]
CRTL 15	88.06	10.63	32	62.87	10.15	30	1.4%	25.19 [20.02, 30.36]
CRTL 16	62.22	7.51	27	60.93	8.32	27	2.0%	1.29 [-2.94, 5.52]
CRTL 17	47.22	16.54	36	29.36	12.1	36	0.9%	17.86 [11.17, 24.55]
CRTL 18	76.89	90.7	27	65.11	86.71	27	0.0%	11.78 [-35.55, 59.11]
CRTL 19	36.06	15.93	35	25.39	14.23	35	0.9%	10.67 [3.59, 17.75]
CRTL 2	72.25	3.95	30	81	4.33	30	4.3%	-8.75 [-10.85, -6.65]
CRTL 20	78.05	8.11	32	68.38	10.09	32	1.8%	9.67 [5.18, 14.16]
CRTL 21	80.13	4.71	33	67.28	2.58	34	4.7%	12.85 [11.02, 14.68]
CRTL 22	76.36	8.82	33	50	12.44	32	1.4%	26.36 [21.10, 31.62]
CRTL 23	72.42	6,977	38	60.26	7,236	38	0.0%	12.16 [-3183.78, 3208.10]
CRTL 24	59.47	6,845	38	60.26	7,236	38	0.0%	-0.79 [-3167.75, 3166.17]
CRTL 25	16.71	2.1	21	12.92	2.28	26	5.7%	3.79 [2.54, 5.04]
CRTL 26	86	2.75	36	82	4.4	35	4.9%	4.00 [2.29, 5.71]
CRTL 27	77.4	9.1	28	62.6	7.3	28	1.9%	14.80 [10.48, 19.12]
CRTL 28	4.75	2.42	33	4.05	2.16	34	5.9%	0.70 [-0.40, 1.80]
CRTL 29	3.6	0.64	30	3.1	0.7	30	6.8%	0.50 [0.16, 0.84]
CRTL 3	83	7,327	2	76.2	8,108	2	0.0%	6.80 [-15138.57, 15152.17]
CRTL 30	104.12	12.43	38	105.55	11.36	20	1.0%	-1.43 [-7.79, 4.93]
CRTL 31	4	0.65	50	3.73	0.73	51	6.8%	0.27 [0.00, 0.54]
CRTL 32	0.4154	0.18337	56	0.2909	0.26947	56	6.9%	0.12 [0.04, 0.21]
CRTL 33	0.3003	0.20561	58	0.2909	0.26947	56	6.9%	0.01 [-0.08, 0.10]
CRTL 34	86.33	1.76	58	77.12	2.67	27	5.9%	9.21 [8.11, 10.31]
CRTL 35	78.05	8.11	32	68.38	10.09	32	1.8%	9.67 [5.18, 14.16]
CRTL 36	84.14	11.04	32	69.12	18.73	32	0.8%	15.02 [7.49, 22.55]
CRTL 4	76.2	50	30	74.6	3.9	30	0.1%	1.60 [-16.35, 19.55]
CRTL 5	32.36	3.34	25	27.84	2.21	25	5.1%	4.52 [2.95, 6.09]
CRTL 6	81.4	8.35	20	61.1	8.21	19	1.4%	20.30 [15.10, 25.50]
CRTL 7	25.09	9.09	32	13.59	7.02	32	2.1%	11.50 [7.52, 15.48]
CRTL 8	76.93	9.61	27	65.67	6.66	72	2.2%	11.26 [7.32, 15.20]
CRTL 9	68.79	11.644	33	63.94	7.762	32	1.6%	4.85 [0.05, 9.65]
Total (95% CI)			**1191**			**1184**	**100.0%**	**4.23 [3.53, 4.93]**

Heterogeneity: Tau² = 1.85; Chi² = 1250.28, df = 35 (P < 0.00001); I² = 97%
Test for overall effect: Z = 11.84 (P < 0.00001)

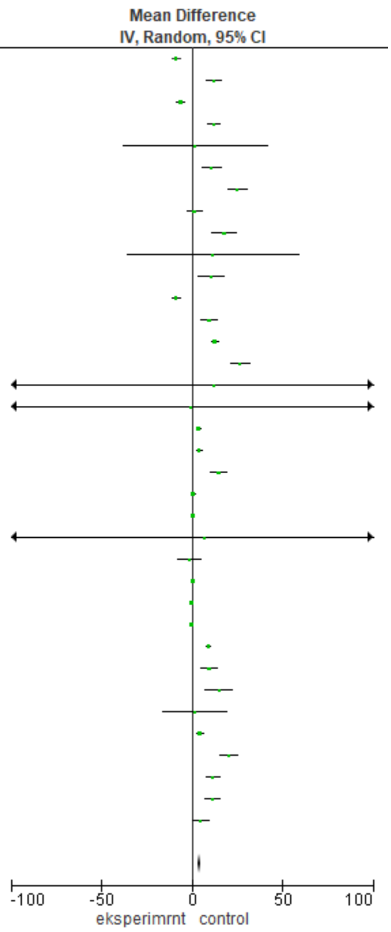

Figure 2. Results of Calculation Meta-Analysis of Critical Thinking

Collaborative Learning of Creative Thinking

Searches of creative thinking literature conducted using keywords and data-based determined resulted in as many as 2215 related studies. Subsequently, the selection process was carried out to discard the study, which was duplication, which resulted in a 1986 study that passed duplication selection. A total of 229 studies were issued because they were not studies that used collaborative learning and were no studies conducted in biology. Furthermore, 1757 studies were obtained to review the article thoroughly. The results of the 1739 studies were discarded because the study did not compare the experimental class with the control class, and the study did not contain basic statistical information that allowed for a meta-analysis. Finally, 18 studies met the criteria for a meta-analysis (Figure3).

A total of 18 studies (1,130 subjects) used collaborative learning as an experimental class to empower creative thinking. A total of 8 studies used problem-based learning, and four used inquiry-based learning, three used project-based learning, two used Discovery learning, and one user group investigation. While for the control class, as many as seven studies reported the use of conventional learning, one study using inquiry, one cooperative learning study, and the rest did not mention the specific learning model.

Based on the level of education, as many as three studies reported intervention at the higher education level, nine studies at the high school level, four studies at the junior level, 1 study at the elementary level, and two studies did not report the level of study. Based on the materials taught, as many as two studies use human anatomical and physiological materials, three studies use ecosystem and environmental materials, one study uses material diversity of living things, one biotechnology study, and ten studies do not report the material used (Appendix 2).

The Figure in Appendix 2 presents each study's effect size calculations and error standards. The highest effect size value was produced by the CRTV 4 study of s.91, and the smallest was produced by the CRTV 1 study with a value of .28. The highest error standard was produced by CRTV study 10 with a value of .76, and the lowest produced by CRTV study 11 with a value of .07. The magnitude of the effect size and standard error values of each study will affect the calculation of the overall meta-analysis.

Figure 4 meta-analysis results show values I^{2}= 100%, P<.05, Mean Difference combined 7.84 with 95%Cl combined range from 4.24, 11.43. A grade I^2 gives the level of diversity of each study. Based on the value I^2= 100% calculation, this shows significant heterogeneity. While the combined Mean Difference value indicates how much influence collaborative learning has on creative thinking. Based on the calculation of a combined Mean Difference value of 7.84, each collaborative learning treatment will affect 7.84 on creative thinking.

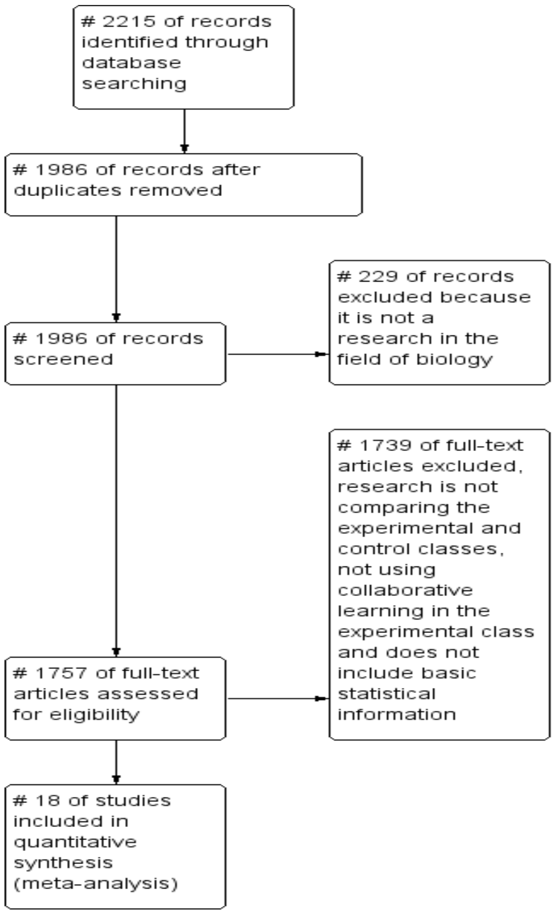

Figure 3. PRISMA Diagram of Creative Thinking

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
CRTV 1	6.32	0.91	27	6.02	1.16	27	6.1%	0.30 [-0.26, 0.86]
CRTV 10	69	11.22	27	57.66	16.04	27	4.8%	11.34 [3.96, 18.72]
CRTV 11	0.7	0.11	31	0.52	0.18	31	6.1%	0.18 [0.11, 0.25]
CRTV 12	56.13	11.3	24	49.41	10.45	22	5.1%	6.72 [0.43, 13.01]
CRTV 13	16.28	5.37	21	22.29	4.41	24	5.9%	-6.01 [-8.91, -3.11]
CRTV 14	75.26	6.02	42	80.71	5.94	42	5.9%	-5.45 [-8.01, -2.89]
CRTV 15	86.17	4.72	36	70.25	12.29	32	5.6%	15.92 [11.39, 20.45]
CRTV 16	80	8.3	35	74.93	10.85	35	5.6%	5.07 [0.54, 9.60]
CRTV 17	77.37	10.51	37	66.37	11.04	34	5.4%	11.00 [5.98, 16.02]
CRTV 18	72.19	10.74	33	66.07	11.22	32	5.4%	6.12 [0.78, 11.46]
CRTV 2	20.31	16.27	48	64.27	19.83	46	4.9%	-43.96 [-51.31, -36.61]
CRTV 3	73.79	14.63	33	58.94	18.28	33	4.7%	14.85 [6.86, 22.84]
CRTV 4	76.8	5.57	25	6.1	8.42	25	5.7%	70.70 [66.74, 74.66]
CRTV 5	29.2	6.17	25	32.12	4.32	25	5.9%	-2.92 [-5.87, 0.03]
CRTV 6	27.6	5.48	30	10.93	5.48	30	5.9%	16.67 [13.90, 19.44]
CRTV 7	80	8.3	35	74.93	10.85	35	5.6%	5.07 [0.54, 9.60]
CRTV 8	74.55	7.29	33	55.63	8.7	32	5.7%	18.92 [15.01, 22.83]
CRTV 9	76.45	4.4	28	63.75	5.3	28	5.9%	12.70 [10.15, 15.25]
Total (95% CI)			**570**			**560**	**100.0%**	**7.84 [4.24, 11.43]**

Heterogeneity: $Tau^2 = 55.10$; $Chi^2 = 1817.40$, df = 17 (P < 0.00001); $I^2 = 99\%$
Test for overall effect: Z = 4.28 (P < 0.0001)

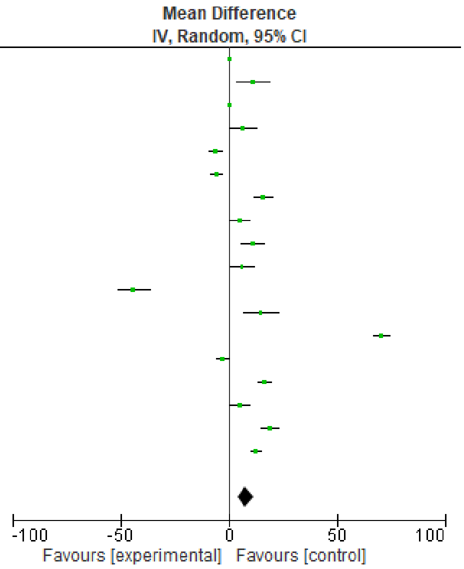

Figure 4. Results of a Meta-Analysis of Creative Thinking

Collaborative Learning of Metacognitive skill Abilities

A metacognitive skills literature search was conducted using predefined keywords and data-based results in 1382 related studies. Furthermore, the selection process was carried out to discard the study, which was duplication, which resulted in 1216 studies passing duplication selection. A total of 659 studies were issued because they were not studies that used collaborative learning and were no studies conducted in biology. A further 557 studies were obtained for a thorough review of the article. The results of the 543 studies were discarded because the study did not compare the experimental class with the control class, and the study did not contain basic statistical information that allowed for a meta-analysis. Finally, a total of 14 studies met the criteria for a meta-analysis (Figure 5).

Fourteen studies (916 subjects) used collaborative learning as an experimental class to empower metacognitively. 4 studies used problem-based learning, eight used inquiry-based learning, one used project-based learning, and 1 used Discovery learning. Five studies reported the use of conventional learning, and the rest did not specify the learning model.

Based on the level of education, as many as one study reported intervention at the higher education level, 11 studies at the high school level, two studies at the junior level. Based on the material taught, as many as six studies use human anatomical and physiological materials, three use ecosystem and environmental materials, and the remaining five studies do not report the material used (Appendix 3).

The Figure in Appendix 3 presents each study's effect size calculations and error standards. The highest effect size value was produced by the MTGV 1 study of 11.39, and the smallest was produced by the MTGV 5 study with a value of .23. The highest error standard was produced by the MTGV 2 study with a value of .91, and the lowest produced by the MTGV 1 study with a value of .11. The amount of effect size and standard error values of each study will affect the calculation of the overall meta-analysis.

Figure 6 meta-analysis results show values $I^2 = 100\%$, P<,05, Mean Difference combined 8.70 with 95%Cl combined range from 2.71, 14.68. A grade I^2 gives the level of diversity of each study. Based on the value $I^2 = 100\%$ calculation, this shows significant heterogeneity. While the combined Mean Difference value indicates how much influence collaborative learning has on creative thinking. Based on the calculation of a combined Mean Difference value of 8.70, it means that each collaborative learning treatment will have an effect of 8.70 on metacognitive skill.

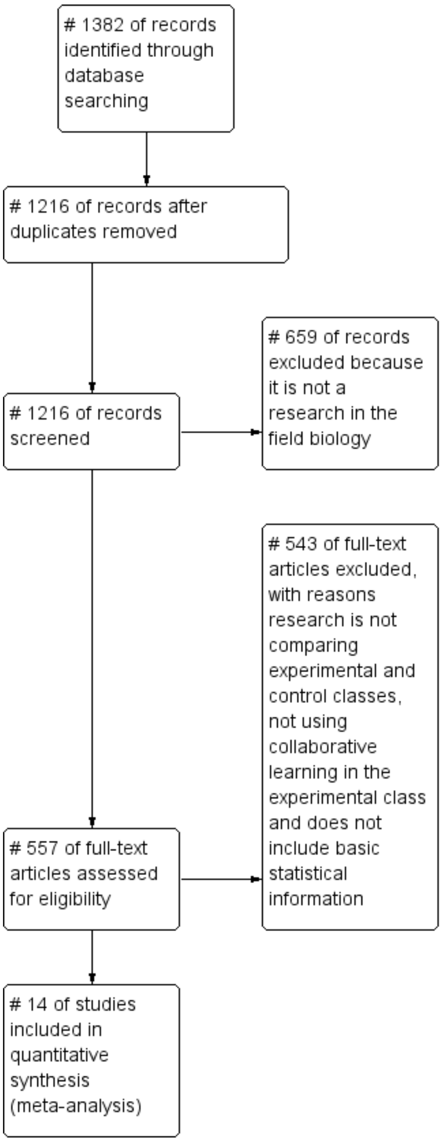

Figure 5. Metacognitive skill PRISMA diagram

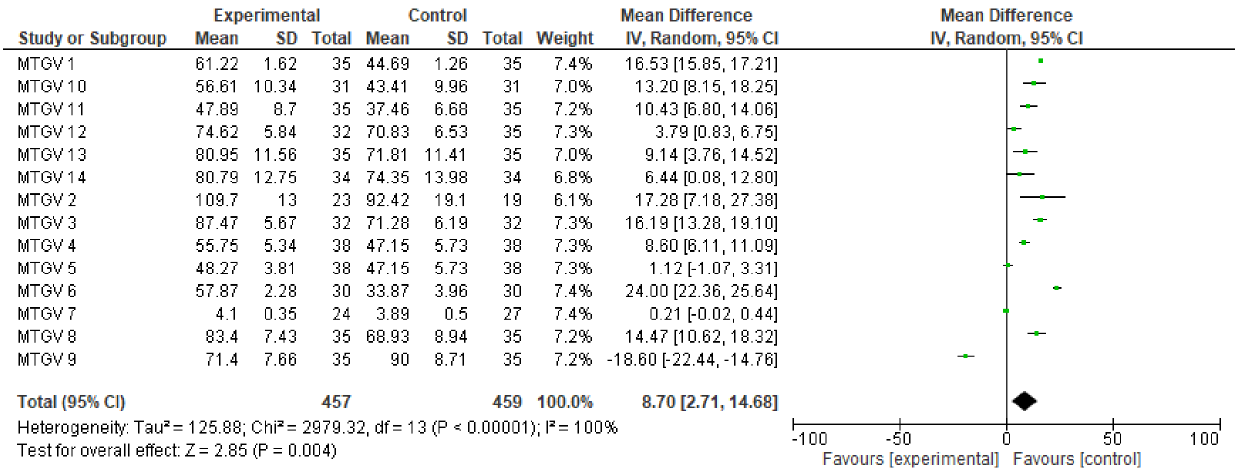

Figure 6. Results of Metacognitive Skill Meta-Analysis Calculations

Publication of Bias and Quality of Study

Assessment of the quality of studies from biased publications is carried out with an assessment rubric from Cochrane (Bryant et al., 2005) modified according to the type of educational research. The assessment process is conducted selectively to assess the quality of studies based on sample determination techniques, including randomization techniques, sample and instrument measurement, data analysis, data delivery, study reporting, and other biases. The assessment results showed that all studies were eligible for inclusion in the meta-analysis study. For more details, the results of the assessment of the quality of the study can be seen in Appendix 4.

Discussion

The Effect of Collaborative Learning on Critical Thinking on Biology Learning

As an essential task of educational institutions, critical thinking at various levels of education has been studied in various contexts and participants. Given the non-uniform conclusions about the influence of learning on critical thinking, systematic studies are needed to synthesize individual studies' results empirically. The study used 37 individual studies with the effect of collaborative learning on critical thinking.

The empirical studies of critical thinking learning show results that vary in methodological characteristics such as design, participant characteristics, taught material, and implementation treatment. After performing the overall effect size calculation, the authors examined significant variability between the studies. Heterogeneity testing tests are conducted, where the test results show I^2 by 97% with a *p-value* greater than .05. This result suggests that the variability of the study is statistically significant. In other words, the measure of treatment effects is inconsistent and varies with each other. The results are due to studies incorporated into the study different from each other in research design, treat experimental and control classes, participants, and taught materials.

The study's findings reinforce that effective collaborative learning interventions encourage critical thinking skills (Khoshneshin, 2011; M. Lee et al., 2014; Y.-H. Lee, 2015; Mandusic & Blaskovic, 2015; Rokhaniyah, 2016; Saiz Sanchez et al., 2014). The effect size of collaborative learning treatment in this meta-analysis aligns with similar studies such as Kong et al., (2014) & Miterianifa et al., (2019) and review literature (Alsaleh, 2020; Lai, 2011; Tang & Sung, 2012).

Collaborative learning can theoretically enhance students in empowering high-level thinking. Collaborative learning can enhance students' critical thinking by asking, analyzing, synthesizing, interpreting, reasoning, and inferring (MacGregor, 1990; Thorndahl & Stentoft, 2020). During collaborative learning, students work together in small groups to solve the problems provided (Johnson & Johnson, 2009; Seibert, 2021; Thomassen & Stentoft, 2020). In a collaborative learning environment, learners are challenged socially and emotionally when they listen to different perspectives and articulate and defend their ideas (Asterhan & Schwarz, 2016; Dillenbourg, 1999; Gillies & Boyle, 2008).

The process of student interaction in collaborative learning is critical in empowering thinking, reasoning, analyzing, and elaborating on each other's learning material (Warsah et al., 2021). In addition, social interaction can help students understand each other, complement competence, empathize with each other (De Hei et al., 2015; Isohätälä et al., 2020). Collaborative learning facilitates students to increase learning focus, increase motivation, encourage students to learn continuously, improve the quality of learning, bind learning outcomes, and achieve better academic achievement (R. Kusumawati et al., 2019; M. Lee et al., 2014; Saiz et al., 2015; Saiz Sanchez et al., 2014)

The Effect of Collaborative Learning on Creative Thinking on Biological Learning

The search results of empirical studies of creative thinking learning vary in methodological characteristics such as design, participant characteristics, taught material, and implementation treatment. After performing the overall effect size calculation, the authors examined significant variability between the studies. Heterogeneity testing is conducted, where the test results show I^2 by 100% with a *p*-value greater than .05. This result suggests that the variability of the study is statistically significant. In other words, the measure of treatment effects is inconsistent and varies with each other. The results are due to studies incorporated into the study different from each other in research design, treat experimental and control classes, participants, and taught materials.

The study's findings reinforce that collaborative learning interventions effectively encourage creative thinking skills (Daud et al., 2012; Glăveanu, 2010; Hadzigeorgiou et al., 2012; Lin et al., 2016; Michalopoulou, 2014). The magnitude of the effect size of collaborative learning treatment in this meta-analysis is in line with other similar studies such as Chang et al. (2016).

Empowering creative thinking in learning is intended to train students in overcoming many problems in a rapidly changing life (Häkkinen et al., 2017). Use of learning Collaborative collaboration can help students understand concepts and connect concepts they already have with the real world (Daud et al., 2012; Ramirez & Monterola, 2019). During collaborative learning, students have the opportunity to communicate with peers, present and defend ideas, actively exchange opinions (Johnson & Johnson, 2009; Laal & Ghodsi, 2012),

During the collaborative learning process, students activate the knowledge they get by discussing groups so that various assumptions arise over the problem at hand, after which students propose possible solutions based on the literature that matches the given problem (Alt & Raichel, 2020; Bos, 2020; Carrió et al., 2020; Chang et al., 2016; Deep et al., 2020). Collaborative interaction in group activities can promote team members in exchanging ideas and sharing viewpoints with fellow group members (Cheng, 2013), produce new outputs such as ideas, understanding, and solutions to problems

(Chang et al., 2016), so that this collaborative learning is highly recommended to contract with group members who can empower creative thinking and generate innovations (Grossen, 2008). These findings align with previous research that showed that group learning and the stimulus of authentic problems influence creative thinking (Tateishi, 2011). Providing stimulus problems during collaborative learning becomes very important to note (DeHaan, 2009). Problem stimulus plays an important role in constructing new knowledge from the point of view of creative thinking (Baillie, 2006; Bengi, 2015; Daud et al., 2012; Eragamreddy, 2013; Hadzigeorgiou et al., 2012; Tateishi, 2011) *like fluency, elaboration, flexibility, originality* (Bayindir & Inan, 2008; Lucas, 2016; Shaheen, 2010; Tateishi, 2011).

The heterogeneity of group members influences increased creative thinking skills. Students raised and educated in different environments will acquire different knowledge, cognitive processes, and value systems. Therefore, it is highly likely that collaborative learning will result in diverse, innovative ideas. When group individuals face problems, their cognitive diversity can provide an opportunity to see the problem from a new perspective to create unique concepts and design a variety of creative ideas (Tateishi, 2011).

The Effect of Collaborative Learning on Metacognitive Skill Abilities on Biological Learning

The results of collaborative learning research literature searches on metacognitive skill biological learning showed results that varied both in determining research methodology, design, participant characteristics, taught materials, and implementation treatment. After performing the overall effect size calculation, the authors examined significant variability between the studies. Heterogeneity testing is conducted, where the test results show I^2 by 100% with a *p*-value > .05. This finding suggests that the variability of the study is statistically significant. In other words, the measure of treatment effects is inconsistent and varies with each other. The results are due to studies incorporated into the study different from each other in research design, treat experimental and control classes, participants, and taught materials.

Collaborative learning provides an opportunity for students to seek information from a variety of learning resources to build their knowledge (Amalia, 2018; Hill et al., 2020; Le et al., 2018; Leeder & Shah, 2016; Zhang & Cui, 2018). The process of building their knowledge gained during small group discussions completes daily life's process (Ramirez & Monterola, 2019). Metacognitive skill in collaborative learning is supported by a theory of social constructivism that emphasizes the importance of social interaction in student delivery (Flavell, 1979; Livingston, 1997).

Metacognitive skill in collaborative learning is defined as the group's ability to reflect on the cognitive abilities of the group as well as the ability to plan, monitor, and evaluate group activities during collaborative learning to gain group knowledge together (Biasutti & Frate, 2018). Metacognitive skill empowerment during collaborative learning is done by providing authentic problems of everyday life. By providing the correct problems, students will be stimulated to dig up information that is already owned and bumped with the problems presented so that there is a knowledge gap (Shin et al., 2020; Song & Park, 2020).

The knowledge gap will stimulate students to evaluate the extent of the knowledge they possess, identify what knowledge they do not already have, plan how to acquire knowledge, and evaluate the process of gaining their new knowledge (Akturk & Sahin, 2011; Branigan & Donaldson, 2020; Cho & Linderman, 2019; Irwin, 2017; Kim & Lim, 2019; Lindner et al., 2021; Livingston, 1997; Mahdavi, 2014; Shea & Frith, 2019; Winne et al., 2013; Zheng et al., 2019). In collaborative learning settings, students are helped to solve problems through learning planning that effectively involves knowing the problem, understanding the problem, understanding the problem the solution needs to look for, and understanding effective strategies for solving it with peers (Kwon et al., 2013; Namdar & Shen, 2018; Pifarre & Cobos, 2010; Winne et al., 2013; Zheng et al., 2019).

Conclusion

This meta-analysis conference summarizes the current state of collaborative learning of critical thinking, creative thinking, and metacognitive skills in biological learning. This research examines the influence of collaborative learning on critical thinking, creative thinking, and metacognitive skills on biological learning. The findings revealed that the average collaborative learning affects critical thinking, creative thinking, and metacognitive skills in biological learning.

Although this study reviewed and concluded previous research on collaborative learning of the ability to think critically, creatively, and metacognitively in biological learning, this study is not the end of a collaborative study of critical thinking, creative thinking, and metacognitive skills in biological learning, advanced implementation research on this learning still has to be done so that later in the future researchers can reveal more profound results.

Recommendations

As input for the next researcher, reporting research on the implementation of collaborative learning should then report in full their studies, especially related to basic statistical information and other supporting information so that more studies can be qualified for analysis. Finally, our hope from these research findings can advance our understanding of collaborative learning and its implementation of biological learning to improve the quality of education.

Limitations

The strengths of this review are as follows: systematic review and meta-analysis include only studies that provide more reliable evidence for combined analysis; research is conducted in several significant databases, and related articles are filtered as much as possible; The quality of the studies included is moderate, and the overall sample size is quite large so that the results may reflect the actual effects of collaborative learning. However, some limitations should not be ignored. First, thesis and dissertation research are not included in this review, so that related data in the dissertation can be omitted; second, for critical thinking, creative thinking, and metacognitive skills to have been measured by different measurements in each study, the self-reported scale may not comprehensively assess critical thinking, creative thinking, and metacognitive skills.

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Authorship Contribution Statement

Dani Ramdani: Conceptualization, design, data acquisition, analysis, writing, drafting manuscript. Herawati Susilo: Editing/reviewing, supervision, final approval. Suhadi: Data analysis, data interpretation, critical revision of manuscript. Sueb: Data acquisition, data analysis, technical support.

References

Aiman, U., & Hasyda, S. (2020). The influence of process oriented guided inquiry learning (POGIL) model assisted by realia media to improve scientific literacy and critical thinking skill of primary school students. *European Journal of Educational Research, 9*(4), 1635–1647. https://doi.org/10.12973/eu-jer.9.4.1635

Aisyafahmi, D., Suratno, & Yushardi. (2019). The analysis of pattren on empowering metacognition skills with models based on problem based learning. *Journal of Physics: Conference Series*, *1211*, 012103. https://doi.org/10.1088/1742-6596/1211/1/012103

Akturk, A. O., & Sahin, I. (2011). Literature review on metacognition and its measurement. *Procedia - Social and Behavioral Sciences, 15*, 3731–3736. https://doi.org/10.1016/j.sbspro.2011.04.364

Alsaleh, N. J. (2020). Teaching critical thinking skills: Literature review. *Turkish Online Journal of Educational Technology*, *19*(1), 21–39.

Alt, D., & Raichel, N. (2020). Problem-based learning, self- and peer assessment in higher education: Towards advancing lifelong learning skills. *Research Papers in Education* Advance online publication. https://doi.org/10.1080/02671522.2020.1849371

Amalia, E. R. (2018). *Collaborative learning: The concepts and practices in the classroom* [Preprint]. Open Science Framework. https://doi.org/10.31219/osf.io/xn67t

Amin, A. M., Corebima, A. D., Zubaidah, S., & Mahanal, S. (2020). The correlation between metacognitive skills and critical thinking skills at the implementation of four different learning strategies in animal physiology lectures. E*uropean Journal of Educational Research, 9(*1), 143–163. https://doi.org/10.12973/eu-jer.9.1.143

Amin, I., & Sukestiyarno, Y. (2015). Analysis metacognitive skills on learning mathematics in high school. *International Journal of Education and Research, 3*(3), 213–222. https://bit.ly/3PA2cvY

Asterhan, C. S. C., & Schwarz, B. B. (2016). Argumentation for learning: Well-trodden paths and unexplored territories. *Educational Psychologist*, *51*(2), 164–187. https://doi.org/10.1080/00461520.2016.1155458

Astriani, D., Susilo, H., Suwono, H., Lukiati, B., & Purnomo, A. (2020). Mind mapping in learning models: A tool to improve student metacognitive skills. *International Journal of Emerging Technologies in Learning*, *15*(6), 4–17. https://doi.org/10.3991/ijet.v15i06.12657

Baillie, C. (2006). Enhancing students' creativity through creative-thinking techniques. In N. Jackson, M. Oliver, M. Shaw, & J. Wisdom (Eds.), *Developing creativity in higher education*. Routledge. https://bit.ly/3ltrZIM

Bayindir, N., & Inan, H. Z. (2008). Theory into practice: Examination of teacher practices in supporting children's creativity and creative thinking. *Ozean Journal of Social Science, 1*(1), 91-96.

Bengi, B. (2015). Creative and critical thinking skills in problem-based learning environments. *Journal of Gifted Education and Creativity, 2*(2), 71–71. https://doi.org/10.18200/JGEDC.2015214253

Biasutti, M., & Frate, S. (2018). Group metacognition in online collaborative learning: Validity and reliability of the group metacognition scale (GMS). *Educational Technology Research and Development, 66*(6), 1321–1338. https://doi.org/10.1007/s11423-018-9583-0

Borenstein, M., Hedges, L., & Rothstein, H. (2007). *Introduction to meta-analysis.* John Wiley & Sons; https://bit.ly/3lr8Y9x

Bos, D. M. V. (2020). Use of problem based learning activity to improve attitudes regarding inter-professional collaborative teamwork in mental health nursing students: An evaluation study. *Nurse Education in Practice*, *49,* 102908. https://doi.org/10.1016/j.nepr.2020.102908

Branigan, H. E., & Donaldson, D. I. (2020). Teachers matter for metacognition: Facilitating metacognition in the primary school through teacher-pupil interactions. *Thinking Skills and Creativity, 38,* 100718. https://doi.org/10.1016/j.tsc.2020.100718

Bryant, J., Clegg, A., Sidhu, M., Brodin, H., Royle, P., & Davidson, P. (2005). Systematic review of the Sugarbaker procedure for pseudomyxoma peritonei. *Journal of British Surgery, 92*(2), 153–158. https://doi.org/10.1002/bjs.4862

Carrió, M., Rodríguez, G., & Baños, J.-E. (2020). Effect of PBL implementation on student and teacher perceptions of improvement in 21st century skills. *BMC Medical Education.* Advance online publication. https://doi.org/10.21203/rs.2.24744/v1

Chalkiadaki, A. (2018). A systematic literature review of 21st century skills and competencies in primary education. *International Journal of Instruction, 11*(3), 1–16. https://doi.org/10.12973/iji.2018.1131a

Chang, J. W., Wang, T.-I., Lee, M.-C., Su, C.-Y., & Chang, P.-C. (2016). Impact of using creative thinking skills and open data on programming design in a computer-supported collaborative learning environment. In J. M. Spector, C.-C. Tsai, D. G. Sampson, Kinshuk, R. Huang, N. S. Chen, & P. Resta (Eds.), *IEEE 16th International Conference on Advanced Learning Technologies (ICALT 2016)* (pp. 396–400). IEEE Computer Society- Coonference Publishing Service (CPS). https://doi.org/10.1109/ICALT.2016.78

Chen, J., Wang, M., Kirschner, P. A., & Tsai, C. C. (2018). The role of collaboration, computer use, learning environments, and supporting strategies in CSCL: A meta-analysis. *Review of Educational Research, 88*(6), 799–843. https://doi.org/10.3102/0034654318791584

Cheng, H.-H. (2013). Student team creativity in information system development: Social capital perspective. *Journal of Software, 8*(9), 2134–2141. https://doi.org/10.4304/jsw.8.9.2134-2141

Cho, Y. S., & Linderman, K. (2019). Metacognition-based process improvement practices. *International Journal of Production Economics, 211,* 132–144. https://doi.org/10.1016/j.ijpe.2019.01.030

Chusni, M. M., Saputro, S., & Rahardjo, S. B. (2021). Student's critical thinking skills through discovery learning model using e-learning on environmental change subject matter. *European Journal of Educational Research, 10*(3), 1123–1135. https://doi.org/10.12973/eu-jer.10.3.1123

Coffman, T. (2012). *Using inquiry in the classroom: Developing creative thinkers and information literate students*. R&L Education Publisher.

Cohen, L., Manion, L., & Morrison, K. (2000). *Research methods in education* (5th ed.). Routledge. https://doi.org/10.4324/9780203224342

Cooke, M., & Moyle, K. (2002). Students' evaluation of problem-based learning. *Nurse Education Today, 22*(4), 330–339. https://doi.org/10.1054/nedt.2001.0713

Cooper, H., Hedges, L. V., & Valentine, J. C. (2019). *The handbook of research synthesis and meta-analysis* (2nd ed.). Russell Sage Foundation. https://doi.org/10.7758/9781610448864

Daud, A. M., Omar, J., Turiman, P., & Osman, K. (2012). Creativity in science education*. Procedia - Social and Behavioral Sciences*, *59*, 467–474. https://doi.org/10.1016/j.sbspro.2012.09.302

De Hei, M. S. A., Strijbos, J.-W., Sjoer, E., & Admiraal, W. (2015). Collaborative learning in higher education: Lecturers' practices and beliefs. *Research Papers in Education*, *30*(2), 232–247. https://doi.org/10.1080/02671522.2014.908407

Deep, S., Ahmed, A., Suleman, N., Abbas, M. Z., Nazar, U., & Razzaq, H. S. A. (2020). The problem-based learning approach towards developing soft skills: A systematic review. *The Qualitative Report, 25*(11), 4029–4054. https://doi.org/10.46743/2160-3715/2020.4114

DeHaan, R. L. (2009). Teaching Creativity and Inventive Problem Solving in Science. *CBE—Life Sciences Education, 8*(3), 172–181*.* https://doi.org/10.1187/cbe.08-12-0081

Dillenbourg, P. (Ed.). (1999). *Collaborative learning: Cognitive and computational approaches* (1st ed). Pergamon.

Ellianawati, Mufiatunnikmah, S., Setyaningsih, N. E., & Subali, B. (2020). Profile of creative thinking abilities of students measured by multi representation-based creative thinking assessment. *Journal of Physics: Conference Series, 1567*(2), 022047. https://doi.org/10.1088/1742-6596/1567/2/022047

Eragamreddy, D. N. (2013). Teaching creative thinking skills. *International Journal of English Language & Translation Studies*, *1*(2), 124-145.

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry. *American Psychologist, 34*(10), 906-911. https://doi.org/10.1037/0003-066X.34.10.906

Gillies, R. M., & Boyle, M. (2008). Teachers' discourse during cooperative learning and their perceptions of this pedagogical practice. *Teaching and Teacher Education, 24*(5), 1333–1348. https://doi.org/10.1016/j.tate.2007.10.003

Glass, G. V. (2006). *Meta-analysis: The quantitative synthesis of research findings*. Routledge. https://doi.org/10.4324/9780203874769

Glăveanu, V. P. (2010). Paradigms in the study of creativity: Introducing the perspective of cultural psychology. *New Ideas in Psychology, 28*(1), 79–93. https://doi.org/10.1016/j.newideapsych.2009.07.007

Green, S. (2005). Systematic reviews and meta-analysis. *Singapore Medical Journal, 46*(6), 270-274. https://bit.ly/3PAvkTS

Greenstein, L. M. (2012). *Assessing 21st century skills: A guide to evaluating mastery and authentic learning*. Corwin Press.

Grossen, M. (2008). Methods for studying collaborative creativity: An original and adventurous blend. *Thinking Skills and Creativity*, *3*(3), 246–249. https://doi.org/10.1016/j.tsc.2008.09.005

Hadzigeorgiou, Y., Fokialis, P., & Kabouropoulou, M. (2012). Thinking about creativity in science education. *Creative Education, 3*(5), 603–611. https://doi.org/10.4236/ce.2012.35089

Häkkinen, P., Järvelä, S., Mäkitalo-Siegl, K., Ahonen, A., Näykki, P., & Valtonen, T. (2017). Preparing teacher-students for twenty-first-century learning practices (PREP 21): A framework for enhancing collaborative problem-solving and strategic learning skills. *Teachers and Teaching, 23*(1), 25–41. https://doi.org/10.1080/13540602.2016.1203772

Higgins, J. P., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M. J., & Welch, V. A. (Eds.). (2019). *Cochrane handbook for systematic reviews of interventions* (2nd ed.). John Wiley & Sons. https://doi.org/10.1002/9781119536604

Hill, R., Woodward, M., & Arthur, A. (2020). Collaborative learning in practice (CLIP): Evaluation of a new approach to clinical learning. *Nurse Education Today, 85*, 104295. https://doi.org/10.1016/j.nedt.2019.104295

Hillmayr, D., Ziernwald, L., Reinhold, F., Hofer, S. I., & Reiss, K. M. (2020). The potential of digital tools to enhance mathematics and science learning in secondary schools: A context-specific meta-analysis. *Computers & Education, 153,* 103897. https://doi.org/10.1016/j.compedu.2020.103897

Huang, B., Zheng, L., Li, C., Li, L., & Yu, H. (2013). Effectiveness of problem-based learning in Chinese dental education: A meta-analysis. *Journal of Dental Education, 77*(3), 377–383. https://doi.org/10.1016/j.compedu.2020.103897

Hunaepi, Firdaus, L., Samsuri, T., Susantini, E., & Raharjo. (2020). Biology prospective teachers' critical thinking disposition and critical thinking skills of IKIP Mataram. *Journal of Physics: Conference Series, 1464*(1), 012031. https://doi.org/10.1088/1742-6596/1464/1/012031

Hwang, W.-Y., Chen, N.-S., Dung, J.-J., & Yang, Y.-L. (2007). Multiple representation skills and creativity effects on mathematical problem solving using a multimedia whiteboard system. *Journal of Educational Technology & Society, 10*(2), 191–212. https://bit.ly/3wvT0RV

Irawan, F., Zubaidah, S., Sulisetijono, & Astriani, M. (2021). Does Remap-STAD have the potential to promote students' creative thinking skills? *AIP Conference Proceedings, 2330*(1), 030029. https://doi.org/10.1063/5.0043179

Irwin, L. (2017). Metacognition: A concept analysis. *Archives of Psychiatric Nursing, 31*(5), 454–456. https://doi.org/10.1016/j.apnu.2017.06.012

Isohätälä, J., Näykki, P., & Järvelä, S. (2020). Cognitive and socio-emotional interaction in collaborative learning: Exploring fluctuations in students' participation. *Scandinavian Journal of Educational Research, 64*(6), 831–851. https://doi.org/10.1080/00313831.2019.1623310

Johnson, D. W., & Johnson, R. T. (2009). An educational psychology success story: Social interdependence theory and cooperative learning. *Educational Researcher, 38*(5), 365–379. https://doi.org/10.3102/0013189X09339057

Kaufman, J. C., & Sternberg, R. J. (Eds.). (2006). *The international handbook of creativity*. Cambridge University Press. https://doi.org/10.1017/CBO9780511818240

Khoshneshin, Z. (2011). Collaborative critical thinking in online environment. *Procedia - Social and Behavioral Sciences, 30*, 1881–1887. https://doi.org/10.1016/j.sbspro.2011.10.366

Kim, J. Y., & Lim, K. Y. (2019). Promoting learning in online, ill-structured problem solving: The effects of scaffolding type and metacognition level. *Computers & Education, 138*, 116–129. https://doi.org/10.1016/j.compedu.2019.05.001

Kong, L.-N., Qin, B., Zhou, Y., Mou, S., & Gao, H.-M. (2014). The effectiveness of problem-based learning on development of nursing students' critical thinking: A systematic review and meta-analysis. *International Journal of Nursing Studies, 51*(3), 458–469. https://doi.org/10.1016/j.ijnurstu.2013.06.009

Kusumawati, G., Lestari, S. R., & Saptasari, M. (2021). Implementation of e-modules endocrine system based of problem based learning to improve students' creative thinking skills and cognitive learning outcomes. *AIP Conference Proceedings, 2330*, 030026. https://doi.org/10.1063/5.0043314

Kusumawati, R., Hobri, & Hadi, A. F. (2019). Implementation of integrated inquiry collaborative learning based on the lesson study for learning community to improve students' creative thinking skill. *Journal of Physics: Conference Series, 1211*, 012097. https://doi.org/10.1088/1742-6596/1211/1/012097

Kwon, K., Hong, R.-Y., & Laffey, J. M. (2013). The educational impact of metacognitive group coordination in computer-supported collaborative learning. *Computers in Human Behavior, 29*(4), 1271–1281. https://doi.org/10.1016/j.chb.2013.01.003

Kyndt, E., Raes, E., Lismont, B., Timmers, F., Cascallar, E., & Dochy, F. (2013). A meta-analysis of the effects of face-to-face cooperative learning. Do recent studies falsify or verify earlier findings? *Educational Research Review, 10*, 133–149. https://doi.org/10.1016/j.edurev.2013.02.002

Laal, M., & Ghodsi, S. M. (2012). Benefits of collaborative learning. *Procedia - Social and Behavioral Sciences, 31*, 486–490. https://doi.org/10.1016/j.sbspro.2011.12.091

Lai, E. R. (2011). Critical thinking: A literature review. *Pearson's Research Reports, 6*(1), 40–41.

Larson, L., & Miller, T. N. (2011). 21st century skills: Prepare students for the future. *Kappa Delta Pi Record, 47*(3), 121–123. https://doi.org/10.1080/00228958.2011.10516575

Larson, L., Miller, T. N., & Ribble, M. (2010). 5 Considerations for digital age leaders: What principals and district administrators need to know about tech integration today. *Learning & Leading with Technology, 37*(4), 12–15.

Le, H., Janssen, J., & Wubbels, T. (2018). Collaborative learning practices: Teacher and student perceived obstacles to effective student collaboration. *Cambridge Journal of Education, 48*(1), 103–122. https://doi.org/10.1080/0305764X.2016.1259389

Lee, M., Kim, H., & Kim, M. (2014). The effects of Socratic questioning on critical thinking in web-based collaborative learning. *Education as Change, 18*(2), 285–302. https://doi.org/10.1080/16823206.2013.849576

Lee, Y.-H. (2015). Facilitating critical thinking using the C-QRAC collaboration script: Enhancing science reading literacy in a computer-supported collaborative learning environment. *Computers & Education, 88,* 182–191. https://doi.org/10.1016/j.compedu.2015.05.004

Leeder, C., & Shah, C. (2016). Collaborative information seeking in student group projects. *Aslib Journal of Information Management. 68*(5), 526-544. https://doi.org/10.1108/AJIM-12-2015-0190

Leny, Syahmani, Ningsih, F., & Sanjaya, R. E. (2020). Guided inquiry assisted concept map to improve students metacognition skills. *Journal of Physics: Conference Series, 1422*, 012036. https://doi.org/10.1088/1742-6596/1422/1/012036

Leonard, P. E., & Leonard, L. J. (2001). The collaborative prescription: Remedy or reverie? *International Journal of Leadership in Education, 4*(4), 383–399. https://doi.org/10.1080/13603120110078016

Lin, M., Preston, A., Kharrufa, A., & Kong, Z. (2016). Making L2 learners' reasoning skills visible: The potential of Computer Supported Collaborative Learning Environments. *Thinking Skills and Creativity*, *22,* 303–322. https://doi.org/10.1016/j.tsc.2016.06.004

Lindner, M. A., Eitel, A., Barenthien, J., & Köller, O. (2021). An integrative study on learning and testing with multimedia: Effects on students' performance and metacognition. *Learning and Instruction*, *71,* 101100. https://doi.org/10.1016/j.learninstruc.2018.01.002

Listiana, L., Susilo, H., Suwono, H., & Suarsini, E. (2016). Empowering students' metacognitive skills through new teaching strategy (group investigation integrated with think talk write) in biology classroom. *Journal of Baltic Science Education, 15*(3), 391-400. https://doi.org/10.33225/jbse/16.15.391

Livingston, J. A. (1997). *Metacognition: An overview*. Educational Resources Information Center. https://bit.ly/3lqDXmr

Lucas, B. (2016). A five-dimensional model of creativity and its assessment in schools. *Applied Measurement in Education, Taylor & Francis, 29*(4), 278–290. https://doi.org/10.1080/08957347.2016.1209206

MacGregor, J. (1990). Collaborative learning: Shared inquiry as a process of reform. *New Directions for Teaching and Learning, 1990*(42), 19-30. https://doi.org/10.1002/tl.37219904204

Magno, C. (2010). The role of metacognitive skills in developing critical thinking. *Metacognition and Learning, 5*(2), 137–156. https://doi.org/10.1007/s11409-010-9054-4

Mahdavi, M. (2014). An overview: Metacognition in education. *International Journal of Multidisciplinary and Current Research, 2*(6), 529–535. https://bit.ly/3sOMpjr

Mandusic, D., & Blaskovic, L. (2015). The impact of collaborative learning to critically thinking. *Trakia Journal of Science, 13*(1), 426–428. https://doi.org/10.15547/tjs.2015.s.01.073

Michalopoulou, A. (2014). Inquiry-based learning through the creative thinking and expression in early years education. *Creative Education*, *5*, 377-385. https://doi.org/10.4236/ce.2014.56047

Miterianifa, Trisnayanti, Y., Khoiri, A., & Ayu, H. D. (2019). Meta-analysis: The effect of problem-based learning on students' critical thinking skills. *AIP Conference Proceedings, 2194*(1), 020064. https://doi.org/10.1063/1.5139796

Moeti, B., Killion Mgawi, R., & Smitta Moalosi, W. T. (2016). Critical thinking among post-graduate diploma in education students in higher education: Reality or fuss? *Journal of Education and Learning*, *6*(2), 13-24. https://doi.org/10.5539/jel.v6n2p13

Muhdhar, M. H. I. A., Faruq, M. K., Sari, M. S., Sumberartha, I. W., & Mardiyanti, L. (2021). The effectiveness of the project-based learning-based ethnobotany module of Karang Kitri towards critical thinking skills. *AIP Conference Proceedings*, *2330*(1), 030006. https://doi.org/10.1063/5.0043107

Munandar, U. (2009). *Kreatifitas pengembangan anak berbakat* [Talented child development creativity]. Rineka Cipta.

Munandar, U. (2012). *Pengembangan kreativitas anak berbakat* [Creative development of gifted children]. Departemen Pendidikan & Kebudayaan.

Namdar, B., & Shen, J. (2018). Knowledge organization through multiple representations in a computer-supported collaborative learning environment. *Interactive Learning Environments, 26*(5), 638–653. https://doi.org/10.1080/10494820.2017.1376337

Nurhalizah, S., Zubaidah, S., Mahanal, S., & Setiawan, D. (2020). RICOSRE for the empowerment of students' creative thinking skills. *AIP Conference Proceedings, 2215*, 030010. https://doi.org/10.1063/5.0000560

Nusantari, E., Abdul, A., Damopolii, I., Alghafri, A. S. R., & Bakkar, B. S. (2021). Combination of discovery learning and metacognitive knowledge strategy to enhance students' critical thinking skills. *European Journal of Educational Research, 10*(4), 1781–1791. https://doi.org/10.12973/eu-jer.10.4.1781

Pascarella, E. T., Martin, G. L., Hanson, J. M., Trolian, T. L., Gillig, B., & Blaich, C. (2014). Effects of diversity experiences on critical thinking skills over 4 years of college. *Journal of College Student Development, 55*(1), 86–92. https://doi.org/10.1353/csd.2014.0009

Pascarella, E. T., & Terenzini, P. T. (2005). *How college affects students: A third decade of research* (Vol. 2). Jossey-Bass, An Imprint of Wiley.

Paul, R., & Elder, L. (2019). *The nature and functions of critical & creative thinking.* Rowman & Littlefield.

Perry, A., & Hammond, N. (2002). Systematic reviews: The experiences of a PhD student. *Psychology Learning & Teaching, 2*(1), 32–35. https://doi.org/10.2304/plat.2002.2.1.32

Pifarre, M., & Cobos, R. (2010). Promoting metacognitive skills through peer scaffolding in a CSCL environment. *International Journal of Computer-Supported Collaborative Learning,* 5(2), 237–253. https://doi.org/10.1007/s11412-010-9084-6

Rahman, S. R., Herna, H., Pujiastuti, I. P., & Fausan, M. M. (2020). RQA learning strategy in the biology classroom and its effect on students' metacognitive awareness. *AIP Conference Proceedings, 2215*, 030013. https://doi.org/10.1063/5.0000578

Rakes, C. R., Ronau, R. N., Bush, S. B., Driskell, S. O., Niess, M. L., & Pugalee, D. K. (2020). Mathematics achievement and orientation: A systematic review and meta-analysis of education technology. *Educational Research Review, 31*, 100337. https://doi.org/10.1016/j.edurev.2020.100337

Ramirez, H. J. M., & Monterola, S. L. C. (2019). Co-creating scripts in computer-supported collaborative learning and its effects on students' logical thinking in earth science. *Interactive Learning Environments*. Advance online publication. https://doi.org/10.1080/10494820.2019.1702063

Retnawati, H., Apino, E., Kartianom, Djidu, H., & Anazifa, R. D. (2018). *Pengantar analisis meta* [Introduction to meta analysis]. Prama Publisihing.

Ridlo, S., & Lutfiya, F. (2017). The correlation between metacognition level with self-efficacy of biology education college students. *Journal of Physics: Conference Series*, *824,* 012067. https://doi.org/10.1088/1742-6596/824/1/012067

Rohrbeck, C. A., Ginsburg-Block, M. D., Fantuzzo, J. W., & Miller, T. R. (2003). Peer-assisted learning interventions with elementary school students: A meta-analytic review. *Journal of Educational Psychology, 95*(2), 240–257*.* https://doi.org/10.1037/0022-0663.95.2.240

Rokhaniyah, H. (2016). The implementation of collaborative learning to enhance the students' critical thinking in writing. *At-Ta'dib, 11*(1), 73-87*.* https://doi.org/10.21111/at-tadib.v11i1.627

Roschelle, J. (1992). Learning by collaborating: Convergent conceptual change. *Journal of the Learning Sciences, 2*(3), 235–276. https://doi.org/10.1207/s15327809jls0203_1

Roseth, C. J., Johnson, D. W., & Johnson, R. T. (2008). Promoting early adolescents' achievement and peer relationships: The effects of cooperative, competitive, and individualistic goal structures. *Psychological Bulletin, 134*(2), 223–246. https://doi.org/10.1037/0033-2909.134.2.223

Saiz, C., Rivas, S. F., & Olivares, S. (2015). Collaborative learning supported by rubrics improves critical thinking. *Journal of the Scholarship of Teaching and Learning, 15*(1), 10–19. https://doi.org/10.14434/josotl.v15i1.12905

Saiz Sanchez, C., Fernandez Rivas, S., & Olivares Moral, S. (2014). Collaborative learning supported by rubrics improves critical thinking. *Journal of the Scholarship of Teaching and Learning*, *15*(1), 10–19. https://doi.org/10.14434/josotl.v15i1.12905

Seibert, S. A. (2021). Problem-based learning: A strategy to foster generation Z's critical thinking and perseverance. *Teaching and Learning in Nursing*, *16*(1), 85–88. https://doi.org/10.1016/j.teln.2020.09.002

Shaheen, R. (2010). Creativity and education. *Creative Education, 1*(3), 166-169. https://doi.org/10.4236/ce.2010.13026

Shea, N., & Frith, C. D. (2019). The global workspace needs metacognition. *Trends in Cognitive Sciences, 23*(7), 560–571. https://doi.org/10.1016/j.tics.2019.04.007

Shin, Y., Kim, D., & Song, D. (2020). Types and timing of scaffolding to promote meaningful peer interaction and increase learning performance in computer-supported collaborative learning environments. *Journal of Educational Computing Research, 58*(3), 640–661. https://doi.org/10.1177/0735633119877134

Siswati, B. H., & Corebima, A. D. (2020). The correlation regression equations between metacognitive skills and concept gaining of science and biology of Indonesian students. *Journal of Physics: Conference Series, 1465*, 012043. https://doi.org/10.1088/1742-6596/1465/1/012043

Smith, B. L., & MacGregor, J. T. (1993). *What is collaborative learning?.* ResearchGate. https://bit.ly/3wwdc6o

Song, Y., & Park, S. (2020). Literature review and meta-analysis of problem-based learning in nursing students. *Journal of Korean Academy of Fundamentals of Nursing*, *27*(3), 246–258. https://doi.org/10.7739/jkafn.2020.27.3.246

Srinivas, H. (2011). *Collaborative learning: What is collaborative learning?* The global development research center. https://bit.ly/3ltUlSV

Starnes, D. S., Yates, D., & Moore, D. S. (2010). *The practice of statistics.* Macmillan.

Sung, Y.-T., Yang, J.-M., & Lee, H.-Y. (2017). The effects of mobile-computer-supported collaborative learning: Meta-analysis and critical synthesis. *Review of Educational Research, 87*(4), 768–805. https://doi.org/10.3102/0034654317704307

Suwono, H., Adi, W. C., & Suarsini, E. (2019). Guided inquiry-blended learning (GI-BL) to enhance the critical thinking skill of undergraduate biology students. *AIP Conference Proceedings, 2081*, 030019. https://doi.org/10.1063/1.5094017

Tang, L.-C., & Sung, H.-C. C. (2012). The Effectiveness of problem-based learning on nursing students' critical thinking: A systematic review. *JBI Evidence Synthesis, 10*(57), 3907–3916*.* https://doi.org/10.11124/jbisrir-2012-14

Tateishi, I. (2011). *Impact of group collaboration on the improvement of individual creative thinking ability* [Doctoral dissertation, Brimingham Young University]. BYU ScholarsArchive. https://bit.ly/38xRJkp

Thomassen, A. O., & Stentoft, D. (2020). Educating students for a complex future: Why integrating a problem analysis in problem-based learning has something to offer. *Interdisciplinary Journal of Problem-Based Learning, 14*(2)*.* https://doi.org/10.14434/ijpbl.v14i2.28804

Thorndahl, K. L., & Stentoft, D. (2020). Thinking critically about critical thinking and problem-based learning in higher education: A scoping review. *Interdisciplinary Journal of Problem-Based Learning, 14*(1). https://doi.org/10.14434/ijpbl.v14i1.28773

Tumewu, W. A., Wulan, A. R., & Sanjaya, Y. (2017). Comparison between project-based learning and discovery learning toward students' metacognitive strategies on global warming concept. *AIP Conference Proceedings, 1848*(1), 060013. https://doi.org/10.1063/1.4983981

Utami, N. M. S., & Astawan, I. G. (2020). *Meta-analisis pengaruh model problem based learning terhadap hasil belajar IPA* [Meta-analysis of the effect of problem based learning models on science learning outcomes]. *Jurnal Pedagogi dan Pembelajaran, 3*(3), 416-427. https://bit.ly/39H1k8E

van Laar, E., van Deursen, A. J., van Dijk, J. A., & de Haan, J. (2020). Determinants of 21st-century skills and 21st-century digital skills for workers: A systematic literature review. *Sage Open, 10*(1), 1-14. https://doi.org/10.1177%2F2158244019900176

van Leeuwen, A., & Janssen, J. (2019). A systematic review of teacher guidance during collaborative learning in primary and secondary education. *Educational Research Review, 27,* 71–89. https://doi.org/10.1016/j.edurev.2019.02.001

Villalba, E. (2017). Critical thinking in relation to creativity. *Reference Module in Neuroscience and Biobehavioral Psychology*, *2017,* 1–4. https://doi.org/10.1016/B978-0-12-809324-5.06160-5

Wahyu, W., Kurnia, & Eli, R. N. (2016). Using problem-based learning to improve students' creative thinking skills on water purification. *AIP Conference Proceedings, 1708*, 040008. https://doi.org/10.1063/1.4941158

Wanah, H. N., Zubaidah, S., Susanto, H., & Astriani, M. (2021). Using Remap-NHT to enhance students' critical thinking skills in biology. *AIP Conference Proceedings, 2330*(1), 030035. https://doi.org/10.1063/5.0043289

Warsah, I., Morganna, R., & Uyun, M. (2021). The impact of collaborative learning on learners' critical thinking skills. *International Journal of Instruction, 14*(2), 443–460. https://doi.org/10.29333/iji.2021.14225a

Winne, P. H., Hadwin, A. F., & Perry, N. E. (2013). Metacognition and computer-supported collaborative learning. In C. E. Hmelo-Silver, C. A. Chinn, C. K. K. Chan & A. O'Donnell (Eds.), *The international handbook of collaborative learning* (pp. 462–479). Routledge/Taylor & Francis Group.

Xie, C., Cheung, A. C. K., Lau, W. W. F., & Slavin, R. E. (2020). The effects of computer-assisted instruction on mathematics achievement in mainland china: A meta-analysis. *International Journal of Educational Research*, *102,* 101565. https://doi.org/10.1016/j.ijer.2020.101565

Yennita, Y., & Zukmadini, A. Y. (2021). Problem-based learning (PBL) and blended learning in improving critical thinking skills and student learning activities in biochemistry courses. *Journal of Physics: Conference Series, 1731,* 012007. https://doi.org/10.1088/1742-6596/1731/1/012007

Yunita, Y., Juandi, D., Tamur, M., Adem, A. M. G., & Pereira, J. (2020). A meta-analysis of the effects of problem-based learning on students' creative thinking in mathematics. *Beta: Jurnal Tadris Matematika, 13*(2), 104–116. https://doi.org/10.20414/betajtm.v13i2.380

Yuwentin, O., Mahardika, I. K., Nuriman, Sudiatmika, A. A. I. A. R., & Sugiartana, I. W. (2020). The development of think together about science in society (TToSS) learning model to increase critical thinking skill in science lesson. *Journal of Physics: Conference Series, 1465*, 012042. https://doi.org/10.1088/1742-6596/1465/1/012042

Zhang, J., & Cui, Q. (2018). Collaborative learning in higher nursing education: A systematic review. *Journal of Professional Nursing, 34*(5), 378–388. https://doi.org/10.1016/j.profnurs.2018.07.007

Zheng, L., Li, X., Zhang, X., & Sun, W. (2019). The effects of group metacognitive scaffolding on group metacognitive behaviors, group performance, and cognitive load in computer-supported collaborative learning. *The Internet and Higher Education*, *42,* 13–24. https://doi.org/10.1016/j.iheduc.2019.03.002

ŽivkoviĿ, S. (2016). A model of critical thinking as an important attribute for success in the 21st century. *Procedia - Social and Behavioral Sciences*, *232*, 102–108. https://doi.org/10.1016/j.sbspro.2016.10.034

Zubaidah, S., & Corebima, A. (2020). Refining student's creative thinking through problem oriented project-based learning and student team achievement division. *Journal of Physics: Conference Series*, *1521*, 042022. https://doi.org/10.1088/1742-6596/1521/4/042022

Apendices

Appendix 1. Critical Thinking Data Extraction Results

Code	Author	Experiment	Control	Year	Educational stage	Material	Eksperimen			Kontrol		N	effect size	r	SD pooled	SDiff	VD	SED
							Mean	SD	N	Mean	SD							
CRTL 1	(Anwar, Abdullah, and Apriana 2015)	PBL	Inqury	2014	PT	Ecosystem and environment	72.25	3.95	30	81	4.33	30	2.11	0.73	4.14	3.09	0.10	0.32
CRTL 2	(Apriana and Anwar 2017)	PBL	Inqury	2014	PT	Ecosystem and environment	72.25	3.95	30	81	4.33	30	2.11	0.73	4.14	3.09	0.10	0.32
CRTL 3	(Pujiastutik 2017)	PBL	Conventional	2017	PT	Microbiology	83	7327	2	76.2	8108	2	0.88	0.40	7.73	8.46	4.23	2.06
CRTL 4	(Surya, Khairil, and Razali 2014)	PBL	Conventional	2014	SMA	Human anatomy and physiology	76.2	50	30	74.6	3.9	30	0.05	0.02	35.46	50.06	1.67	1.29
CRTL 5	(Palestina, Samingan, and Apriana 2014)	PBL	Conventional	2014	SMA	Human anatomy and physiology	32.36	3.34	25	27.84	2.21	25	1.60	0.62	2.83	2.61	0.10	0.32
CRTL 6	(Surya and Noviyanti 2017)	PBL	Conventional	2017	SMA	Ecosystem and environment	81.4	8.35	20	61.1	8.21	19	2.45	0.77	8.28	5.56	0.29	0.53
CRTL 7	(Pepo, Arjaya, and Paraniti 2019)	PBL	Conventional	2019	SMA		25.09	9.09	32	13.59	7.02	32	1.42	0.58	8.12	7.63	0.24	0.49
CRTL 8	Kurniahtunnisa, K., Dewi, N. K., & Utami, N. R. (2016)	PBL	Conventional	2016	SMA	Human anatomy and physiology	76.93	9.61	27	65.67	6.66	72	1.36	0.56	8.27	8.04	0.16	0.40
CRTL 9	(Wardani 2015)	PBL	Conventional	2015	SMA	Human anatomy and physiology	68.79	11.644	33	63.94	7.762	32	0.49	0.24	9.90	12.36	0.38	0.62
CRTL 10	(Aida 2018)	PBL	Discovery	2019	SMA	Human anatomy and physiology	73.61	8.20	34	61.62	9.31	32	0.85	0.39	11.40	12.60	0.36	0.60
CRTL 11	(Chairunnisa 2017)	PBL		2017	SMA	Diversity of living things	68.84	4.98	38	75.14	4.67	38	1.37	0.56	8.78	8.24	0.25	0.50
CRTL 12	(Rahmawati 2018)	PBL	PBL +	2018	SMA	Human anatomy and physiology	72.43	4.57	26	60.41	6.84	24	1.31	0.55	4.83	4.60	0.12	0.35
CRTL 13	(MF 2018)	PBL	Conventional	2018	SMA	Ecosystem and environment	85.58	78.53	31	83.87	82.99	32	2.07	0.72	5.82	4.77	0.19	0.44
CRTL 14	(Ariandani and Ansori 2016)	PBL		2016	SMA		76.9	10.4	30	65.9	10.2	30	0.02	0.01	80.79	113.65	3.61	1.90
CRTL 15	(Sihombing, Hutauruk, and Efendi 2018)	PBL		2018	SMP		88.06	10.63	32	62.87	10.15	30	1.07	0.47	10.30	10.60	0.35	0.59
CRTL 16	(Kurniati, Khairil, and Darwin 2019)	PBL	Conventional	2019	SMP		62.22	7.51	27	60.93	8.32	27	2.42	0.77	10.39	7.04	0.23	0.48
CRTL 17	(Aryanti, Surtikanti, and Riandi 2017)	PBL		2017	SMP	Ecosystem and environment	47.22	16.54	36	29.36	12.1	36	0.16	0.08	7.93	10.75	0.40	0.63
CRTL 18	Anesa, D. R., & Ahda, Y. (2021)	PBL		2021	PT	Genetics	76.89	90.7	27	65.11	86.71	27	1.23	0.52	14.49	14.49	0.40	0.63
CRTL 19	Hasanah, M. D., Alberida, H., & Rahmi, Y. L. (2018).	PBL		2018	SMP	Human anatomy and physiology	36.06	15.93	35	25.39	14.23	35	0.13	0.07	88.73	121.26	4.49	2.12
CRTL 20	Astuti, M. Y., Alberida, H., & Rahmi, Y. L (2018	Inqury	Conventional	2018	SMP	Human anatomy and physiology	78.05	8.11	32	68.38	10.09	32	0.71	0.33	15.10	17.47	0.50	0.71
CRTL 21	Elisanti, E., Sajidan, S., & Prayitno, B. A. (2018)	Inqury		2018	SMA	Human anatomy and physiology	80.13	4.71	33	67.28	2.58	34	1.06	0.47	9.15	9.55	0.30	0.55
CRTL 22	Hasan, R., Lukitasari, M., Utami, S., & Anizar, A. (2019	Inqury	Cooperative	2019	SMA	Diversity of living things	76.36	8.82	33	50	12.44	32	3.38	0.86	3.80	2.81	0.08	0.29
CRTL 23	Fitriyani, R., Corebima, A. D., & Ibrohim, I. (2015)	PBL	Conventional	2015	SMA		72.42	6977	38	60.26	7236	38	2.44	0.77	10.78	7.92	0.24	0.49
CRTL 24	Fitriyani, R., Corebima, A. D., & Ibrohim, I. (2015)	Inqury	Conventional	2015	SMA	Cell biology	59.47	6845	38	60.26	7236	38	1.71	0.65	7.11	5.95	0.16	0.40
CRTL 25	Nurlaili, N., Panjaitan, R. G. P., & Yeni, L. F. (2021)	Inqury	Conventional	2021	SMP	Human anatomy and physiology	16.71	2.1	21	12.92	2.28	26	0.11	0.06	7.04	9.68	0.25	0.50
CRTL 26	Suparini, S., Rusdi, R., & Ristanto, R. H. (2020)	Discovery	Discovery	2020	SMA	Human anatomy and physiology	86	2.75	36	82	4.4	35	1.73	0.65	2.19	1.83	0.08	0.28
CRTL 27	Pursitasari, I. D., Suhardi, E., Putra, A. P., & Rachman, I. (2020)	Inqury	Inqury	2020	SMP	Human anatomy and physiology	77.4	9.1	28	62.6	7.3	28	1.09	0.48	3.67	3.92	0.11	0.33
CRTL 28	Sirajudin, N. (2019, April).	PBL	Conventional	2018	PT	Human anatomy and physiology	4.75	2.42	33	4.05	2.16	34	1.79	0.67	8.25	6.88	0.25	0.50
CRTL 29	Alawi, N. H., & Soh, T. M. T. (2019).	PjBL		2019	SMA	Ecosystem and environment	3.60	0.64	30	3.10	0.70	30	0.30	0.15	2.30	3.00	0.09	0.30
CRTL 30	Friedel, C., Irani, T., Rudd, R., Gallo, M., Eckhardt, E., & Ricketts, J. (2(	Inqury		2008	PT	Biotechnology	104.12	12.43	38	105.55	11.36	20	0.74	0.35	0.67	0.77	0.03	0.16
CRTL 31	Hwang, G. J., & Chen, C. H. (2017)	Inqury		2016	SD	Diversity of living things	4	0.65	50	3.73	0.73	51	0.12	0.06	11.91	16.33	0.56	0.75
CRTL 32	Prayogi, S., & Asy'ari, M. (2021)	PBL	Conventional	2021	SMP	Ecosystem and environment	0.4154	0.18337	56	0.2909	0.26947	56	0.39	0.19	0.69	0.88	0.02	0.13
CRTL 33	Prayogi, S., & Asy'ari, M. (2021)	PBL	Conventional	2021	SMP	Ecosystem and environment	0.3003	0.20561	58	0.2909	0.26947	56	0.54	0.26	0.23	0.28	0.01	0.07
CRTL 34	Greenwald, R. R., & Quitadamo, I. J. (2014).	Inqury	Conventional	2014	PT	Human anatomy and physiology	86.33	1.76	58	77.12	2.67	27	0.04	0.02	0.24	0.34	0.01	0.08
CRTL 35	Rahmi, Y. L., Alberida, H., & Astuti, M. Y. (2019, October	Inqury	Conventional	2019	SMP	Human anatomy and physiology	78.05	8.11	32	68.38	10.09	32	4.07	0.90	2.26	1.34	0.03	0.18
CRTL 36	Wardani, I. (2020, June).	Inqury	5E	2020	ID	Diversity of living things	84.14	11.04	32	69.12	18.73	32	1.06	0.47	9.15	9.55	0.30	0.55

SD = primary school
SMP = junior high school
SMA = senior high school
PT = college
ID = incomplete data

Appendix 2. Creative Thinking Data Extraction Results

Code	Author	Experiment	Control	Year	Educational stage	Material	Eksperimen			Kontrol		N	effect size	r	SD pooled	SDiff	VD	SED
							Mean	SD	N	Mean	SD							
CRTV 1	Orozco, J. A., & Yangco, R. T. (2016).	PBL	Conventional	2016	SMA	Ecosystem and environment	6.32	0.91	27	6.02	1.16	27	0.28	0.14	1.04	1.37	0.05	0.23
CRTV 2	Sofyan, A. (2020).	PBL	Conventional	2020	SMA		20.31	16.27	48	64.27	19.83	46	2.42	0.77	18.14	12.66	0.27	0.52
CRTV 3	Lestari, D., & Syamsurizal, S. (2021)	PBL		2021	SMA		73.79	14.63	33	58.94	18.28	33	0.90	0.41	16.55	18.14	0.55	0.74
CRTV 4	Qodratullah, S. T., Milla, H., & Kasmirudin, K. (2019, October)	Inkuiri	Conventional	2019	SMP		76.80	5.57	25	6.10	8.42	25	9.91	0.98	7.14	3.16	0.13	0.36
CRTV 5	Gholamian, A. (2013)	Discovery		2013	SMP		29.20	6.17	25	32.12	4.32	25	0.55	0.26	5.32	6.52	0.26	0.51
CRTV 6	Nofida, A., & Arif, S. (2020)	PBL		2020	SMP		27.60	5.48	30	10.93	5.48	30	3.04	0.84	5.48	3.14	0.10	0.32
CRTV 7	Susanti, F. O., Muttaqin, M., & Listiawati, M. (2017).	Inkuiri	Conventional	2017	SMA	Human anatomy and physiology	80.00	8.30	35	74.93	10.85	35	0.52	0.25	9.66	11.87	0.34	0.58
CRTV 8	Hasan, R., Lukitasari, M., Utami, S., & Anizar, A. (2019).	Inkuiri	Cooperative	2019	ID	Diversity of living things	74.55	7.29	33	55.63	8.70	32	2.36	0.76	8.03	5.67	0.17	0.42
CRTV 9	Anjarwati, P. G. P., Sajidan, S., & Prayitno, B. A. (2018)	PBL		2018	SMA	Ecosystem and environment	76.45	4.40	28	63.75	5.30	28	2.61	0.79	4.87	3.23	0.12	0.34
CRTV 10	Dyah Hayu, N. P., & Riezky Maya P, M. (2015)	Group Investigation	Conventional	2015	SMA		69.00	11.22	27	57.66	16.04	27	0.82	0.38	13.84	15.71	0.58	0.76
CRTV 11	Atmojo, I. R. W., Sajidan, S., Sunarno, W., & Ashadi, A. (2019, October)	Discovery	Inkuiri	2018	PT	Biotechnology	0.70	0.11	31	0.52	0.18	31	1.21	0.52	0.15	0.16	0.01	0.07
CRTV 12	Eren, C. D., & Akinoglu, O. (2012)	PBL		2012	PT		56.13	11.30	24	49.41	10.45	22	0.62	0.29	10.88	12.93	0.56	0.75
CRTV 13	Putri, S. U., Sumiati, T., & Larasati, I. (2019, February)	PJBI	Conventional	2019	SD		16.28	5.37	21	22.29	4.41	24	1.22	0.52	4.91	4.86	0.22	0.46
CRTV 14	Ridlo, Z. R., Nuha, U., Terra, I. W. A., & Afafa, L. (2020, June)	STEM Pjbl		2020	PT		75.26	6.02	42	80.71	5.94	42	0.91	0.41	5.98	6.47	0.15	0.39
CRTV 15	(Milla et al., 2014)	PJBl		2014	SMP	Ecosystem and environment	86.17	4.72	36	70.25	12.29	32	1.71	0.65	9.31	9.90	0.29	0.54
CRTV 16	(Susanti et al., 2017)	Inkuiri		2017	SMA	Human anatomy and physiology	80.00	8.30	35	74.93	10.85	35	0.52	0.25	9.66	11.87	0.34	0.58
CRTV 17	(Pratiwi, 2012)	PBL		2012	ID		77.37	10.51	37	66.37	11.04	34	1.02	0.45	10.78	11.26	0.32	0.56
CRTV 18	(Puspitasari, 2012)	PBL	Conventional	2012	SMA		72.19	10.74	33	66.07	11.22	32	0.56	0.27	10.98	13.29	0.41	0.64

SD = primary school
SMP = junior high school
SMA = senior high school
PT = college
ID = incomplete data

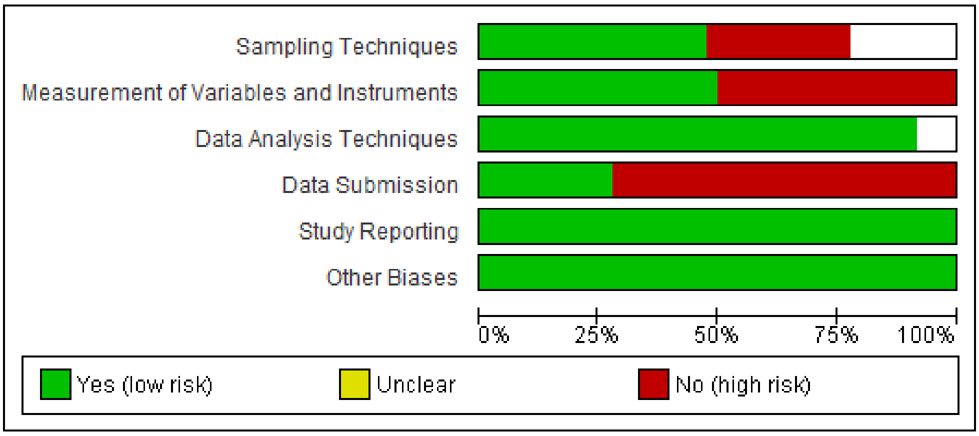
Appendix 3. Metacognitive Skills Data Extraction Results

Code	Author	Experiment	Control	Year	Educational stage	Material	Eksperimen			Kontrol		N	effect size	r	SD pooled	SDiff	VD	SED
							Mean	SD	N	Mean	SD							
MTGV 1	Lelasari, T., Yohanita, A. M., & Damopolii, I. (2021).	Inkuiri		2021	SMA	Human anatomy and physiology	35	61.22	1.62	35	44.69	1.26	11.39	0.98	1.45	0.44	0.01	0.11
MTGV 2	Demirel, M., & TURAN, B. A. (2010)	PBL		2010	SMP		23	109.7	13	19	92.42	19.1	1.06	0.47	16.34	17.37	0.83	0.91
MTGV 3	Mulyani, D. F., & Arif, S. (2021)	PBL		2021	SMP		32	87.47	5.67	32	71.28	6.19	2.73	0.81	5.94	3.72	0.12	0.34
MTGV 4	Fitriyani, R., Corebima, A. D., & Ibrohim, I. (2015)	PBL	Conventional	2015	SMA		38	55.75	5.34	38	47.15	5.73	1.55	0.61	5.54	4.88	0.13	0.36
MTGV 5	Fitriyani, R., Corebima, A. D., & Ibrohim, I. (2015)	Inkuiri	Conventional	2015	SMA		38	48.27	3.81	38	47.15	5.73	0.23	0.11	4.86	6.51	0.17	0.41
MTGV 6	Rahmat, I., Chanunan, S., & Bahri, A. (2018)	Inkuiri	Conventional	2018	SMA		30	57.87	2.28	30	33.87	3.96	7.43	0.97	3.23	1.86	0.06	0.25
MTGV 7	Kuvac, M., & Koc, I. (2019).	PBL	Conventional	2018	PT	Ecosystem and environment	24	4.1	0.35	27	3.89	0.5	0.49	0.24	0.43	0.54	0.02	0.15
MTGV 8	Suwono, H., Susanti, S., & Lestari, U. (2017, March)	Inkuiri		2017	SMA	Human anatomy and physiology	35	83.4	7.43	35	68.93	8.94	1.76	0.66	8.22	6.88	0.20	0.44
MTGV 9	Fitri, A (2019)	Inkuiri		2019	SMA	Human anatomy and physiology	35	71.4	7.66	35	90	8.71	2.27	0.75	8.20	5.87	0.17	0.41
MTGV 10	Hanifah, S. (2017)	Inkuiri		2017	SMA	Human anatomy and physiology	31	56.61	10.34	31	43.41	9.96	1.30	0.55	10.15	9.69	0.31	0.56
MTGV 11	Mahmuda, R. A. (2017)	Inkuiri		2017	SMA	Human anatomy and physiology	35	47.89	8.70	35	37.46	6.68	1.34	0.56	7.75	7.44	0.21	0.46
MTGV 12	Prihandini, D. R. (2018)	Inkuiri	Conventional	2018	SMA	Human anatomy and physiology	32	74.62	5.84	35	70.83	6.53	0.61	0.29	6.19	7.38	0.22	0.47
MTGV 13	(Erianti et al., 2020)	Discovery		2020	SMA	Ecosystem and environment	35	80.95	11.56	35	71.81	11.41	0.80	0.37	11.49	12.90	0.37	0.61
MTGV 14	(Lestari et al., 2017)	PBL		2017	SMA	Ecosystem and environment	34	80.79	12.75	34	74.35	13.98	0.48	0.23	13.38	16.57	0.49	0.70

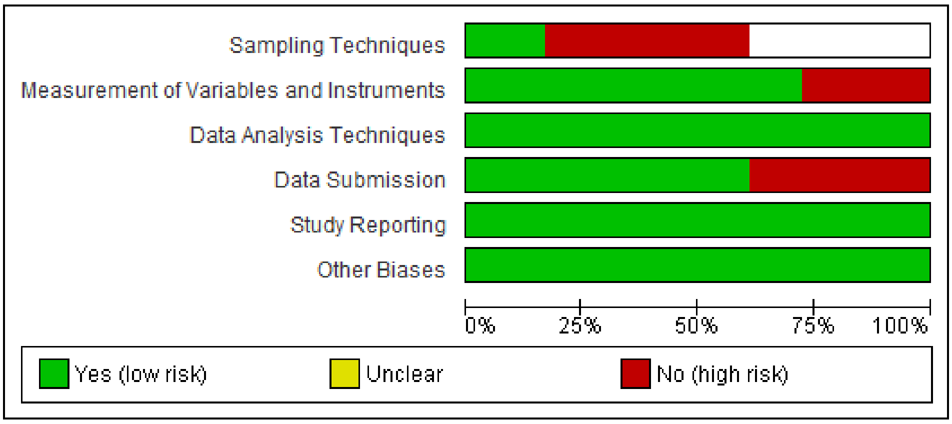
SMP = junior high school
SMA = senior high school
PT = college

Appendix 4. Results of bias publication-quality measurements

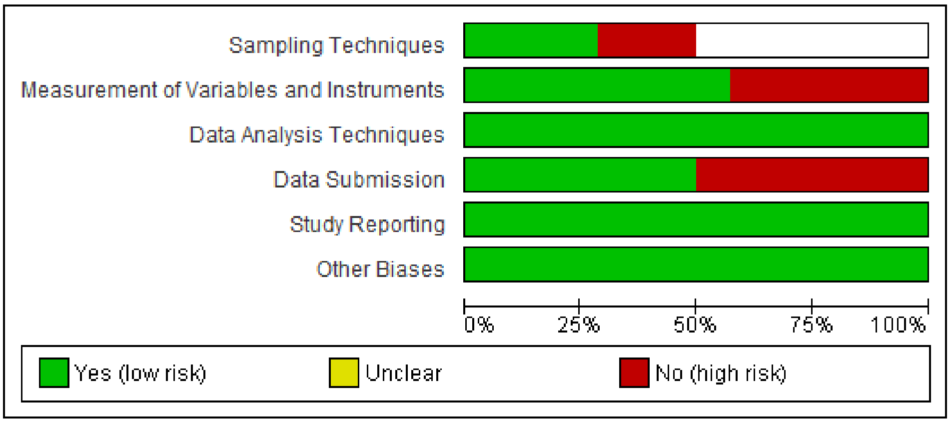
1. Resume results of critical thinking quality studies



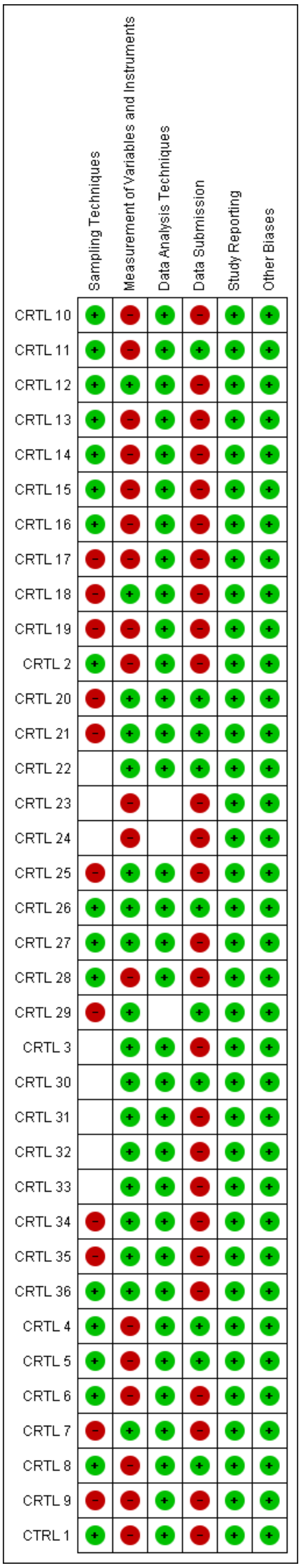
2. Resume results of the quality study of creative thinking



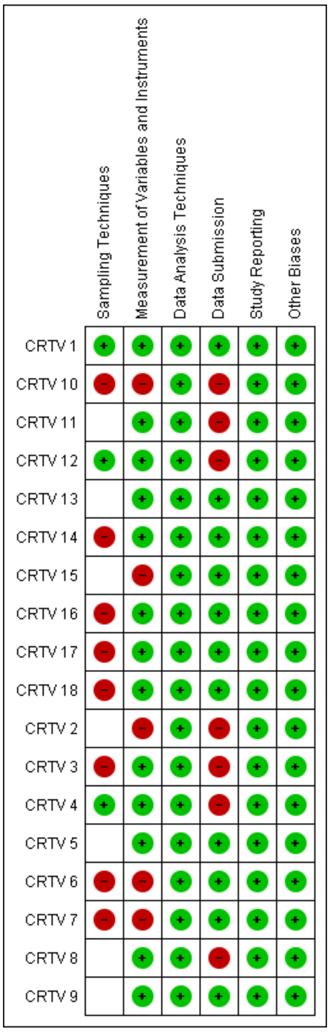
3. Metacognitive study quality resume results



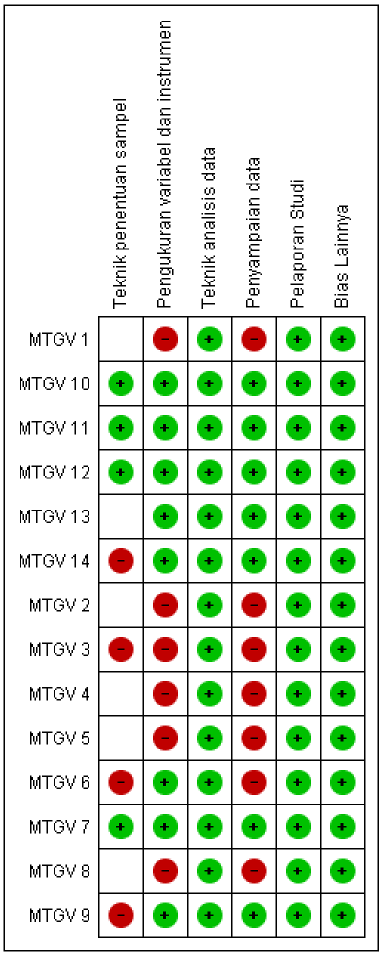
4. Results of measurement of the quality of critical, creative, and metacognitive thinking studies as a whole



Critical Thinking



Creative Thinking



Metacognitive

No.	Criteria	Question
1	Sampling Techniques	Samples are taken randomly
2	Measurement of Variables and Instruments	Studies mention the way variables and instruments are used.
3	Data Analysis Techniques	Studies mention techniques used for data analysis.
4	Data Submission	The data is submitted in full and allows for recalculation.
5	Study Reporting	Studies report in a complex manner and can answer research objectives
6	Other Biases	Study not indicate fraud

Measurement criteria

Color	Criteria
🟢	Yes/High
🔴	No/Low
○ 🟡	Unclear