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Effects of mind mapping-based instruction on student cognitive learning outcomes: a meta-analysis

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Abstract

Mind mapping is a visualization tool used in instruction that can be applied by learners to generate ideas, take notes, organize thinking, and develop concepts. Instruction using mind mapping is becoming increasingly commonly used in education. However, research has produced inconsistent results regarding the effectiveness of mind mapping-based instruction on student learning outcomes. Using the meta-analysis of 21 studies, this study investigates the overall effectiveness of the mind mapping-based instructions on students' learning outcomes in comparison with that of traditional instruction. Mind mapping-based instruction has been found to have a more positive influence on students' cognitive learning outcomes than traditional instruction. Analysis of moderator variables suggests that the subject matter and educational level are important factors in the effectiveness of mind mapping-based instruction. Lower-grade students are more susceptible to the influence of mind mapping-based instruction than higher-grade students, and mind mapping-based instruction helps students improve their cognitive learning outcomes in all subjects, especially in the Science, Technology, Engineering, and Math disciplines.

Keywords Mind mapping · Meta-analysis · Cognitive learning outcomes · Effect size

Introduction

Mind mapping is a powerful learning technique used to structure thoughts using hierarchy and categorization (Buzan & Buzan, 1993). As a note-taking technique, mind mapping enables individuals to organize facts and thoughts in a map format, creating a central image with main themes radiating this image, branches from these showing key images and keywords, and branches forming a connected node structure (Tee et al., 2014). The ideas and the relationships between them are presented in a visual and nonlinear manner (Biktimirov & Nilson, 2006). An image that represents the main topic is placed at the center of a mind map, extended by several major branches in different colors representing the subheadings with smaller attached branches. Unlike the traditional linear note-taking method, mind mapping concentrates on essential keywords and draws clear associations between them. Its radial structure also follows the patterns of reasoning in the mind and reflects the infinite associative nature of the human brain (Buzan & Buzan, 1993). Furthermore, mind mapping is multisensory, and its combination of colors, pictures, and branches makes it a visually stimulating way to study, organize, and store information (Day & Bellezza, 1983). Using colors, images, and keywords, mind mapping can trigger both sides of the human brain and increase its learning potential (Biktimirov & Nilson, 2006).

Mind mapping and other mapping tools, such as concept mapping, knowledge mapping, and graphic organizers, have been widely observed in education. As a visualization tool, mind mapping not only represents a central theme using its connections but also supports the development of creative associations between ideas. Mind mapping is less formal and structured than concept mapping, and it emphasizes diagrams and pictures to aid in association recall; concept

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mapping generally uses hierarchical structure and relational phrases to aid in the understanding of relationships between ideas (Davies, 2011). As an essential part of knowledge management, knowledge mapping can be used as a bridge for implementing a knowledge management system (Al Hakim et al., 2020), whereas mind mapping helps students understand the relationships between knowledge elements. Generally, graphic organizers (e.g., concept maps, knowledge maps, and outlines) are defined as spatial arrangements of words (Stull & Mayer, 2007).

A mind map is built in a free-form manner, with no constraint on its ultimate structure. The flexibility of mind mapping encourages brainstorming and promotes creative thinking (Davies, 2011). Mind mapping can be used to generalize main ideas into a topic, help students remember information, and allow them to plan answers to exam questions (Noonan, 2013). However, as mind mapping only deals with simple hierarchical relationships developed through links, its limitation is obvious for the presentation of complex concepts and relations. Additionally, mind mapping is idiosyncratic, so one person's mind map is difficult for others to read (Eppler, 2006).

In educational practice, a growing number of educators are using mind mapping to assist classroom instruction, and it has been incorporated into curricula to enable teachers to organize and present materials as a pedagogical tool in the instruction process (Dhindsa et al., 2011). Previous studies have reported that mind mapping-based instruction has a positive impact on student learning outcomes, including improving their memory recall (e.g., Farrand et al., 2002), facilitating their reading comprehension (e.g., Abi-El-Mona & Adb-El-Khalick, 2008; Fesel et al., 2016; Khatimah & Rachman, 2018; Kusmaningrum, 2016; Malekzadeh & Bayat, 2015), promoting creative thinking and critical thinking skills (e.g., Davies, 2011; Polat & Aydn, 2020; Zubaidah et al., 2017), and enhancing their learning performance (e.g., Adodo, 2013; Blessing & Olufunke, 2015; Fu et al., 2019).

It should be noted that studies that examine the effectiveness of mind mapping-based instruction to improve students' cognitive learning outcomes have produced mixed results. A majority of studies have reported that mind mapping-based instruction has positive effects on student learning outcomes (e.g., Al-Zyoud et al., 2017; Masnaini et al., 2018), whereas a few studies have identified its negative effects on student learning outcomes (e.g., D'Antoni et al., 2010; Kalyanasundaram et al., 2017). Moreover, the inconsistency of previous results constitutes a rationale for deeper investigative methods, such as meta-analysis, to synthesize the findings of varied observations of similar contexts (Shi et al., 2020b).

Although it has been the object of much study, how far mind mapping-based instruction influences students' cognitive learning outcomes remains unclear. Thus, this study was conducted to provide new quantitative data on the issue using meta-analyses of the highest-quality empirical research available. Particularly, this study (a) explores the effectiveness of mind mapping-based instruction across disciplines in the educational context and (b) investigates the moderators that may influence this effectiveness.

Theoretical background and related works

Mind mapping-based instruction

Mind mapping has been found to be a particularly useful tool for instruction to help students establish a conceptual understanding of disciplinary content, promoting their learning achievements (Abi-El-Mona & Adb-El-Khalick, 2008). Mind mapping was first developed by T. Buzan as a note-taking technique used to save time while keeping the eyes as interested as possible (Buzan & Buzan, 1993). This technique has been used to enhance the problem-solving ability and to overcome certain disadvantages of traditional instructions, in addition to improving note-taking methods (Tsinakos & Thanasis, 2009). Mind mapping enables the graphical visualization of teaching material and of its knowledge structure, which can enhance the brain's desire for knowledge. It can also stimulate students' brain functions, enable the whole brain to actively participate in learning, and enhance memory functions (Liu et al., 2018). Additionally, Buzan and Buzan (1993) found that the use of different symbols, such as graphics, images, colors, and numbers in mind mapping can promote the cultivation of knowledge among learners. Therefore, mind maps can act as a visualization of how students think, understand, organize, and apply knowledge (Somers et al., 2014). Instruction in language skills has also greatly benefited from mind mapping (Al-Zyoud et al., 2017), and it can make the least interesting tasks fun and may improve students' attention to and memorization of study materials. Students who use mind mapping can experience enhanced memory ability and creativity because of the smoother flow of their thoughts (Sugiarto, 2004; Zampetakis et al., 2007).

Because of the characteristics of mind mapping, an increasing number of researchers have studied the effectiveness of mind mapping instruction models in improving students' learning outcomes. However, the results have been inconsistent. Many studies have identified that mind mapping-based instruction has a significant impact on cognitive learning outcomes among students in various subjects and at different educational levels. For example, Al-Zyoud et al. (2017) discussed the potential effects of mind mapping strategies on the development of writing performance in a group of Jordanian students. The results showed a statistically significant difference between the two average scores of the experimental group and the control group. Balim (2013) conducted a study of mind mapping in a seventh-grade science and technology course and found that in terms of cognitive and affective levels, the experimental group and the control group showed significant differences in academic achievement, learning retention, and perceptions of inquiry-learning skill. Meivi Sesanelvira et al. (2019) investigated the effects of using mind mapping methods on the safe food behavior of school-age children. They found that the average score for student knowledge on food safety before and after education by the mind mapping method was significantly improved. Additionally, Guo et al. (2017) found that the addition of mind mapping to the multimodal final exams of pharmacology students improved student achievements in all aspects.

However, several other studies have found that mind mapping-based instruction has no significant differences from traditional lecture-based instruction in students' cognitive learning achievements. For example, Fesel et al. (2016) examined the effects of hypertext strategy training in combination with mind mapping on sixth-graders' strategy use and learning outcomes in hypertext reading strategies. The results showed that experimental group students who were trained in mind mapping produced slightly higher mean scores than control group students, but no significant differences were found. Other studies have found that students who participate in mind mapping-based instruction have even lower academic achievement than traditionally instructed students. For instance, in a quasi-experimental study conducted to explore the impacts of mind map learning strategy on first-year medical students' information retrieval and critical thinking abilities, D'Antoni et al. (2010) investigated the relationship between mind mapping and recall of domain-based information using pre-quiz and post-quiz. They found that students in the mind map group have lower mean scores in the posttest than those members of the control group, although no other significant difference existed between the two groups, which suggested that mind mapping-based instruction has no significant effects on students' learning achievements. Kalyanasundaram et al. (2017) evaluated the impact of mind mapping on information retrieval among medical students in college by calculating their knowledge levels between the groups before the intervention, immediately after the intervention (day 0), and 1 week (day 7) after the intervention. The results showed that the mind map group had lower knowledge gain at day 0 and day 7 than the control group, although no other significant difference was found between the two groups. Thus, the effects of mind mapping-based instruction on cognitive learning outcomes remain unclear.

Meta-analysis and related works

Meta-analysis is a quantitative statistical method used to synthesize and integrate descriptive statistics reported in multiple relevant published and unpublished primary studies that test the same conceptual questions and hypotheses (Glass, 1976; Hedges & Olkin, 1985).

Some meta-analyses of studies of instruction using mind mapping have been published (e.g., Batdi, 2015; Li et al., 2018; Liu et al., 2014). For example, Liu et al. (2014) conducted a meta-analysis of studies published from 1999 to 2013. The final calculated academic effect value was 0.75, the affective effect value was 0.68, and the meta-analyses were likely influenced by country, usage, subject, and achievement. Batdi (2015) examined the effects of mind mapping on learners' academic achievements, attitudes, and retention scores using the meta-analysis method, collecting studies between the years 2005 and 2013. A total of 15 studies were included in the meta-analysis, and the effect size values for academic achievement, attitude, and retention scores were 1.057, 0.627, and 0.431, respectively. The meta-analytic results indicate that mind mapping has a positive effect on learners' academic achievement, attitude, and retention. A meta-analysis conducted by Li et al. (2018) synthesized a total of 60 papers (including journal papers, conference papers, and excellent doctoral dissertation) published from 2007 to 2016, focusing on the exploration of whether mind mapping can effectively improve students' academic achievements, what the effective basic characteristics are, and what the conditions are that affect students' mind mapping. The results indicated an average effect size of 0.763, which suggests that mind mapping-based instruction can effectively improve students' academic performance.

These three studies all determined the effects of mind mapping-based instruction on learners' cognitive learning outcomes using meta-analysis. However, each of the three exhibits a degree of inadequacy and limitation. Liu et al. (2014) examined six moderator variables that could influence the effect size, including the country, subject, educational level, and duration of the study, but other important potential moderator variables, such as pedagogical approach and sample size, were ignored. Moreover, the vast majority of studies (83.7%) included in that meta-analysis were from China alone. There was no analysis of moderator variables in Batdi's (2015) meta-analysis, making it impossible to determine which factors could affect the effectiveness of mind mapping-based instruction. The meta-analysis conducted by Li et al. (2018) featured a broader range of eligible studies, including journal articles, dissertation, and conference papers, but some may not have been peer-reviewed, prompting the concern that the resulting variable quality may have affected the effect size of the meta-analysis leading to a lower-quality meta-analysis.

Additionally, several new empirical studies of the effectiveness of mind mapping-based instruction have been published over the past 3 years, adding new sources for a meta-analysis. This present study, therefore, follows well-defined and strict criteria for the screening of the newer studies published over the last decade, including only high-quality peer-reviewed journal articles for the meta-analysis to determine the effects of mind mapping-based instruction on students' cognitive learning outcomes.

Research questions

To determine the status of students' cognitive learning outcomes in mind mapping-based instruction, the following research questions were proposed in the present study's design and analysis:

1. How does the effectiveness of mind mapping-based instruction compare with that of traditional instruction?
2. What moderator variables influence the effectiveness of mind mapping-based instruction on students' cognitive learning outcomes?

Methodology

Conceptual framework

This study examined student learning outcomes in terms of cognitive learning, which is the quantifiable result of a student's effort in the conduct of a variety of educational activities that take place during instruction (Munawaroh, 2017). Cognitive learning, a key indicator in the evaluation of the quality of education (Michaelowa, 2010), is commonly measured using examinations or assessments and reflects student growth in terms of the measurable level of their academic achievement. A range of factors can affect students' cognitive learning outcomes, both in terms of their scale and direction regarding mind mapping-based instruction and traditional instruction (cf. Li et al., 2018; Liu et al., 2014).

Following the framework proposed by Means et al. (2013) and a review of the moderator variables included in previous meta-analyses (e.g., Hughes & Lyons, 2017; Li et al., 2018; Shi et al., 2020a), a conceptual framework was developed for this study's meta-analysis to guide both the data extraction included in the meta-analysis and the follow-up moderator analysis. The conceptual framework includes three categories: (a) instructional experiences, including pedagogical approach, treatment duration, and pattern of participation; (b) study conditions, including the year of publication, subject matter, and educational level; and (c) research methodology, including study design and sample size. Table 1 presents the conceptual framework of this study. All variables related to the three categories instructional experiences, study conditions, and research methodology were extracted, and variables were analyzed as a potential moderator of the effect size only if enough studies with sufficient data for the variable were included (Shi et al., 2020b).

The pedagogical approach is regarded as one of the most essential distinctions among various mind mapping-based instruction approaches, since different pedagogical approaches, which had varied learning contents, learning activities, and instructional structures, led to different learning experiences (Galvis et al., 2006; Ryan & Reid, 2016). Independent learning (independent individual study) and collaborative learning (interdependent group study) are the two major pedagogical approaches described in the literature. In this study, independent learning generally includes all instructional methods that actively engage students during the learning process, wherein students engage in meaningful learning activities (Crimmins & Midkiff, 2017; Prince, 2004), and collaborative learning refers to the mutual engagement of participants in a coordinated effort to address a problem together (Roschelle & Teasley, 1995). The latter emphasizes student interactions within an interdependent group rather than in learning as a solitary activity, and it offers students the opportunity to develop both cognitive skills and prosocial behaviors (Gilies et al., 2008).

Participation patterns, which influence how a mind map is generated during learning, are another important

Table 1 Conceptual framework

Category	Features	Description
Instructional experiences	Pedagogical approach	Pedagogical approach used by the instructor in the classroom
	Treatment duration	Length of the study
	Pattern of participation	The way teachers and students participate in mind mapping
Study conditions	Year of publication	Year the study was published
	Subject matter	Discipline in which the study was conducted
	Educational level	Population from which the sample was drawn
Research methodology	Study design	The research method used in the study
	Sample size	Number of students involved in the study

characteristic in mind mapping-based instruction. As noted by Li et al. (2018), three patterns of participation relate to the source of mind mapping: student-generated (SG) mind mapping, in which the student independently participates in the generation of the mind mapping; teacher/researcher-provided (TRP) mind mapping, in which the teacher or researcher provides students with the mind mapping directly; and SG & TRP mind mapping, in which the teacher/researcher and students participate in the generation of mind mapping together. Outcomes from this last category show significant moderation of the effects of mind mapping-based instruction on student learning achievement (Li et al., 2018).

Search and selection process

The search and selection process of this study included an initial search and screening, the application of selection criteria, and a final selection and data extraction of related studies, as shown in Fig. 1. To decide whether to include a study in the final review, a title and abstract screening of the initial electronic database searches was conducted, resulting in a preliminary set of full articles for potential final review. After this, a full-text screening of the preliminary full articles was conducted to confirm the relevance of the studies assessed. This two-stage approach proved to be an efficient means of avoiding missing potentially relevant and high-quality studies (Means et al., 2013).

Initial search and screening

A comprehensive search of the literature from 2010 to 2019 was conducted to explore the effectiveness of mind mapping in students' cognitive learning outcomes over the last decade. Key concepts and search terms were developed to capture the literature related to mind mapping-based instruction from an international perspective. The specific search phrases utilized in this study were "mind mapping" OR "mind map" OR "mind mapping and experiment."

The Education Resources Information Centre, Elsevier Science Direct online, Web of Science, EBSCO, ProQuest, Taylor & Francis Online, and Springer Link were selected for searching because together they provide a wide multidisciplinary perspective while controlling the rigor through a limitation to established publications with a wide variety of citation indexes, content sources, countries of origin, and differing perspectives within educational and multidisciplinary domains (MacLeod et al., 2019). The search was restricted to articles written in English and published in peer-reviewed journals. The reference lists of the articles identified through the electronic search were also searched manually. Two researchers searched the databases together and independently selected eligible articles. Any discrepancies were resolved through discussion with a third researcher.

The initial electronic searches across the databases yielded a total of 1726 relevant articles. After deleting 465 duplicate articles (with the same article included in more than one database), the remaining 1261 articles were reviewed with the title and abstract alone, and 1203 articles considered to be irrelevant were excluded. Then, 58 articles were screened with their full-text and checked for eligibility against the selection criteria.

Selection criteria

A comprehensive set of inclusion and exclusion criteria was established to identify all eligible articles (Table 2). Studies were examined to ascertain whether they met the following inclusion criteria: (a) written in English and published in a peer-reviewed journal; (b) used in a rigorous experimental design (e.g., randomized controlled design, controlled quasi-experimental design); (c) reported quantitative data on students' cognitive learning outcomes using objective-based

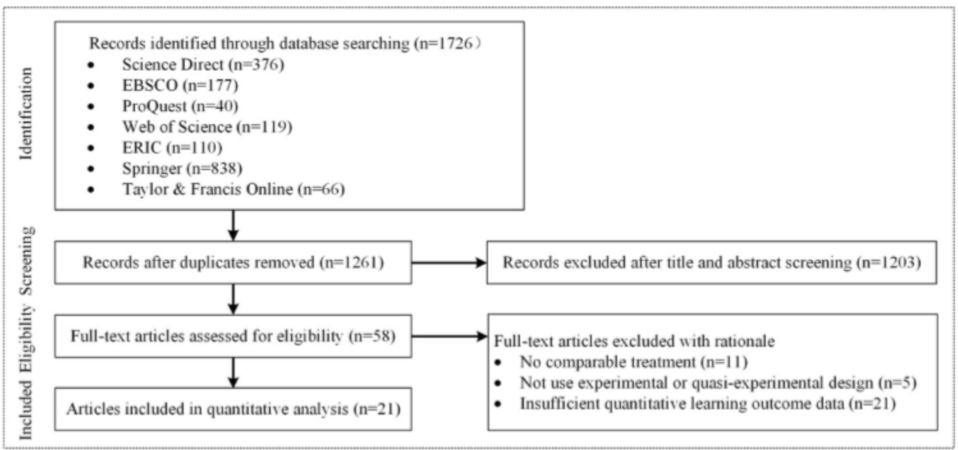

Fig. 1 Flow diagram of the study's search and selection process

Table 2 Selection criteria

Criteria	Inclusion	Exclusion
Time period	Published between 2010 and 2019	Published outside this time period
Language	English	Non-English
Literature type	Peer-reviewed journal articles	Not peer-reviewed journal articles
Research design	Study had an experimental (randomized controlled), or quasi-experimental design Study had a between-subject design comparing mind mapping-based and traditional instruction	Nonexperimental or not quasi-experimental design or no comparison between mind mapping-based and traditional instruction
Results of research	Adequate quantitative data for calculating the effect size or reporting the effect size	Not enough quantitative data for calculating the effect size
Learning outcomes	Cognitive learning outcomes	Noncognitive learning outcomes

assessments (e.g., tests or final exams); and (d) reported at least one comparison between a mind mapping condition with a traditional lecturing condition. Studies that did not meet these four criteria were excluded.

Final selection and data extraction

Using this conceptual framework, we extracted relevant data in terms of the following information from the studies: authors and year of publication, sample size, type of subjects, design (e.g., quasi-experiment or random assignment control), treatment duration, and measurements of cognitive learning outcomes (e.g., examinations). Two researchers independently conducted the data extraction. Discrepancies were resolved through consensus between the two researchers. This resulted in 37 journal articles being rejected from the initial pool of 58 potentially relevant publications. Articles were rejected on the basis of these criteria: there was no comparison between a mind mapping-based classroom and traditional learning environment (n = 11); studies did not use an experimental or quasi-experiment study design (n = 5); or studies did not report empirical research with sufficiently quantitative learning outcome data (n = 21). A total of 21 eligible articles were included in the final meta-analysis.

Data analysis

Review Manager 5.3 software (Cochrane Collaboration, 2014) was used to test the data for heterogeneity and to conduct the meta-analysis. Based on the sample size and the 95% confidence intervals (CI), the effect size of each study was assessed by calculating the standardized mean difference (SMD) from the means and standard deviations of the students' cognitive learning outcome data (e.g., exam scores and posttest scores). Additionally, a variance analysis was used for pooled studies (Shi et al., 2020a). A two-sided p value below 0.05 was regarded as significant for all analyses.

A fixed-effects model or a random-effects model was applied in the meta-analyses in relation to the heterogeneity of the data. The presence of heterogeneity (degree of inconsistency in the studies' results) was detected using the I^2 test (Higgins et al., 2003). Once a heterogeneity was identified, a sensitivity analysis was conducted to assess whether it significantly altered the results of the meta-analysis. Publication bias was also examined using funnel plot shapes and fail-safe numbers (Nfs) to assess the presence of bias in the meta-analysis. Moreover, moderator analyses were conducted to assess which variable(s) in terms of instruction experiences, study conditions, and research methodologies influenced the meta-analysis. This allowed us to examine preset variables in relation to the proposed conceptual framework.

Characteristics of included studies

A total number of 21 articles were included in this review. An examination led to the identification of 21 independent effect sizes. Table 3 shows the characteristics of the 21 included studies. These articles were published from 2010 to 2019 with sample sizes ranging from 22 to 131 participants. A majority of the studies had sample sizes below 100. The total pooled sample size was 1602 (experimental group = 779, control group = 823). The participants came from four levels of education: elementary, junior high school, high school, and university education. The subjects of the studies included chemistry, English, mathematics, medicine, and physics. The experimental methods of these studies included a quasi-experimental design and a random assignment control design. Measurement of these studies included pretests and posttests, questionnaire tests, and final examinations. Most studies were drawn from Scopus, Web of Science (ESCI, SCI, SSCI), ERIC, EBSCO, etc., which ensured that the chosen articles were of high-quality.

Table 3 Characteristics of the 21 independent studies included in the meta-analysis

No	Study (year)	Sample size (E/C)	Educational level	Subject	Method	Treatment duration	Measurements	Source and indexing
1	Al-Zyoud et al. (2017)	40 (20/20)	HSE	English	QED	3 months	Pretest and post-test	SCOPUS/ESCI
2	Ayal et al. (2016)	130 (65/65)	JHSE	Mathematics	QED	1 year	Pretest and post-test	EBSCO/Google Scholar
3	Aydin (2013)	40 (20/20)	ELE	S & T	QED	4 weeks	Pretest and post-test	SSCI
4	Bahadori and Gorjian (2016)	60 (30/30)	UNE	English	RAC	3 weeks	Pretest and post-test	Google Scholar
5	Balim (2013)	64 (32/32)	JHSE	S & T	QED	3 weeks	Pretest and post-test	SCOPUS
6	Bawaneh (2019)	111(54/57)	HSE	Physics	QED	1 semester	Pretest and post-test	SCOPUS
7	Chang, Chiu, & Huang (2018)	61 (31/30)	ELE	History	RAC	Unknow	Pretest and post-test	SSCI
8	D'Antoni et al. (2010)	131 (66/65)	UNE	Medical	QED	205 min	Pretest and post-test	SCI
9	Fesel et al. (2016)	84 (55/29)	ELE	Reading	QED	2 days	Pretest and post-test	SCOPUS/ESCI
10	Fu et al. (2019)	74 (38/36)	UNE	English tourism	QED	18 weeks	Pretest and post-test	SSCI
11	Gagic et al. (2019)	113 (57/56)	ELE	Physics	QED	8 weeks	Pretest and post-test	SCOPUS
12	Guo et al. (2017)	122 (22/100)	UNE	Pharmacology	QED	5 months	Final examination	SCOPUS
13	Hallen and Sangeetha (2015)	60 (30/30)	JHSE	English	RAC	Unknow	Pretest and post-test	ERIC
14	Kalyanasundaram et al. (2017)	64 (32/32)	UNE	Medicine	RAC	1 semester	MCQs	SCOPUS/ESCI
15	Luo (2019)	90 (45/45)	UNE	HFE	RAC	Unknow	Pretest and post-test	SCOPUS/ESCI
16	Masnaini, Copriady, & Osman (2018)	64 (32/32)	HSE	Chemistry	QED	6 weeks	Pretest and post-test	SCOPUS
17	Meivi Sesanelvira et al. (2019)	88 (44/44)	ELE	Health education	QED	3 weeks	Pretest and post-test	SCOPUS/ESCI
18	Mohaidat (2018)	60 (30/30)	JHSE	English	QED	2 months	Pretest and post-test	ERIC
19	Rezapour-Nasrabad (2019)	80 (40/40)	UNE	Nursing	QED	4 sessions	WT and AS	ESCI
20	Sabbah (2015)	22 (14/8)	UNE	English	QED	8 weeks	Pretest and post-test	EBSCO/ProQuest
21	Zhang (2018)	44 (22/22)	UNE	English	RAC	7 weeks	Pretest and post-test	ERIC

E experimental group or mind mapping instructional model, *C* Control group or traditional lecture-based instructional model, *HSE* high school education, *JHSE* Junior high school education, *ELE* elementary education, *UNE* University education, *RAC* random assigned control, *QED* quasi-experiment design, *S & T* Science and Technology, *HFE* health fitness education, *MCQs* multiple choice questions, *WT & AS* written test & assessment sheet, *ESCI* Emerging Sources Citation Index, *SSCI* Social Science Citation Index, *SCI* Science Citation Index, *ERIC* Education Resources Information Center

Results

The present meta-analysis included 21 eligible independent effect sizes, involving 779 subjects exposed to mind mapping-based instruction and 823 subjects exposed to traditional instruction. Because a high heterogeneity was found ($I^2 = 88\%$, $p < 0.001$), a random-effects model was used to pool the data. Of the 21 individual contrasts between mind mapping-based instruction and traditional instruction, 19 reported significantly positive effects that favored the mind mapping-based classroom, whereas two reported negative effects that favored the traditional classroom.

Overall effect size

Overall, the pooled effect size showed a statistically significant difference in students' cognitive learning outcomes, with mind mapping-based instruction generating better learning outcomes than the traditional classrooms (SMD = 0.99, 95% CI 0.68–1.31, $p < 0.001$), as shown in Fig. 2. The reliability of the results was verified through sensitivity analysis by sequentially omitting individual studies. This analysis showed that the pooled effect size favored the mind mapping-based instruction group and did not change the effects found in the initial analysis, which confirmed the high reliability of the pooled effect size and indicated that the mind mapping-based instruction effectively improved students' cognitive learning outcomes.

Publication bias

Publication bias occurs when researchers restrict themselves to publishing their preferred results (Peplow, 2017), and it can be assessed by observing funnel plot shapes and calculating the Nfs. The funnel plot shapes and Nfs were used together to identify publication bias. The shape of the funnel plot shown in Fig. 3 is almost symmetrical, indicating a low chance of publication bias.

Additionally, the Nfs, which estimate the number of unretrieved studies averaging null results needed to bring the overall combined effect size at a nonsignificant level (Rosenthal, 1979), was calculated using the following formula at a significance level of 0.05:

$$Nfs_{0.05} = \left(\frac{\sum Z}{1.645}\right)^2 - k$$

where Z represents the Z-value of each independent effect size and k is the number of included studies. The larger the value of Nfs, especially when it significantly exceeds the critical value $5\,k + 10$ (Rosenthal, 1991), the more robust the mean effect size, and the lower the likelihood of publication bias (Hoeve et al., 2012). In this study, $k = 21$, $\sum Z = 80.79$, and $Nfs_{0.05} = (\frac{\sum Z}{1.645})^2 - k = (97.51/1.645)^2 - 21 = 2391.03 > 115$ $(5{*}21 + 10)$, Nfs is significant, exceeding the critical value of $5\,k + 10$, indicating no sign of publication bias.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Al-Zyoud, Al Jamal, & Baniabdelrahman (2017)	19.45	3.1	20	14.69	2.52	20	4.3%	1.65 [0.92, 2.38]
Ayal, Kusuma, Sabandar, & Dahlan (2016)	26.8	4.22	65	22.18	3.28	65	5.1%	1.22 [0.84, 1.59]
Aydin (2013)	17.25	5.99	20	13.15	4.34	20	4.5%	0.77 [0.12, 1.41]
Bahadori & Gorjian (2016)	23.3	7.55737	30	18.3667	6.68237	30	4.8%	0.68 [0.16, 1.20]
Balım (2013)	15.02	3.39	32	10.14	2.41	32	4.7%	1.64 [1.07, 2.21]
Bawaneh (2019)	17.09	1.84	54	14.22	2.57	57	5.1%	1.27 [0.86, 1.68]
Chang, Chiu, & Huang (2018)	83.26	11.036	31	75.33	7.284	30	4.8%	0.83 [0.31, 1.36]
D'Antoni, Zipp, Olson, & Cahill (2010)	7.64	1.22	66	7.85	1.4	65	5.2%	-0.16 [-0.50, 0.18]
Fesel, Segers, de Leeuw, & Verhoeven (2016)	2.91	0.7	55	2.68	0.5	29	5.0%	0.36 [-0.10, 0.81]
Fu, Lin, Hwang, & Zhang (2019)	29.72	3.27	38	28.08	3.24	36	4.9%	0.50 [0.04, 0.96]
Gagic et al. (2019)	12.63	2.74	57	9.46	3	56	5.1%	1.10 [0.70, 1.49]
Guo et al. (2017)	80.05	7.54	22	68.07	12.77	100	4.9%	0.99 [0.51, 1.47]
Hallen & Sangeetha (2015)	4.7	1.291	30	3.83	1.177	30	4.8%	0.70 [0.17, 1.22]
Kalyanasundaram et al. (2017)	5.4	1.688	32	6	1.688	32	4.9%	-0.35 [-0.85, 0.14]
Luo (2019)	85.87	6.36	45	79.02	8.95	45	5.0%	0.87 [0.44, 1.31]
Masnaini, Copriady, & Osman (2018)	76.63	11.042	32	58.25	10.358	32	4.7%	1.70 [1.12, 2.27]
Mohaidat (2018)	19.667	3.31	30	17.233	3.18	30	4.8%	0.74 [0.22, 1.26]
Rezapour-Nasrabad (2019)	15.55	2.44897	40	13.05	2.97813	40	4.9%	0.91 [0.45, 1.37]
Sabbah (2015)	80.43	10.868	14	70.13	10.999	8	3.8%	0.91 [-0.01, 1.83]
Sesanelvira, Mulyono, & Sukihananto (2019)	13.39	1.528	44	6.57	1.822	44	4.2%	4.02 [3.28, 4.76]
Zhang (2018)	75.23	4.63	22	70.03	5.1	22	4.5%	1.05 [0.41, 1.68]
Total (95% CI)			**779**			**823**	**100.0%**	**0.99 [0.68, 1.31]**

Heterogeneity: Tau² = 0.46; Chi² = 164.84, df = 20 (P < 0.00001); I² = 88%
Test for overall effect: Z = 6.20 (P < 0.00001)

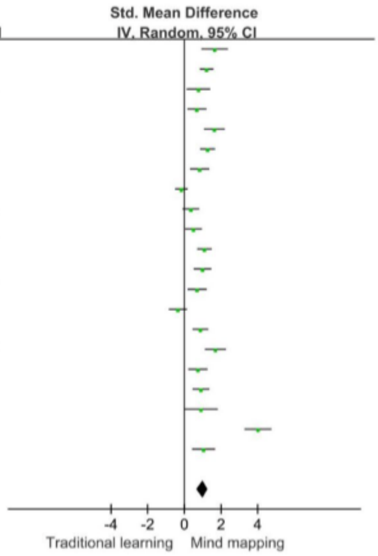

Fig. 2 Forest plot of effect sizes (standardized mean difference) using the random-effects model. *Note: SD* standard deviation, *CI* confidence interval, *IV* inverse variance

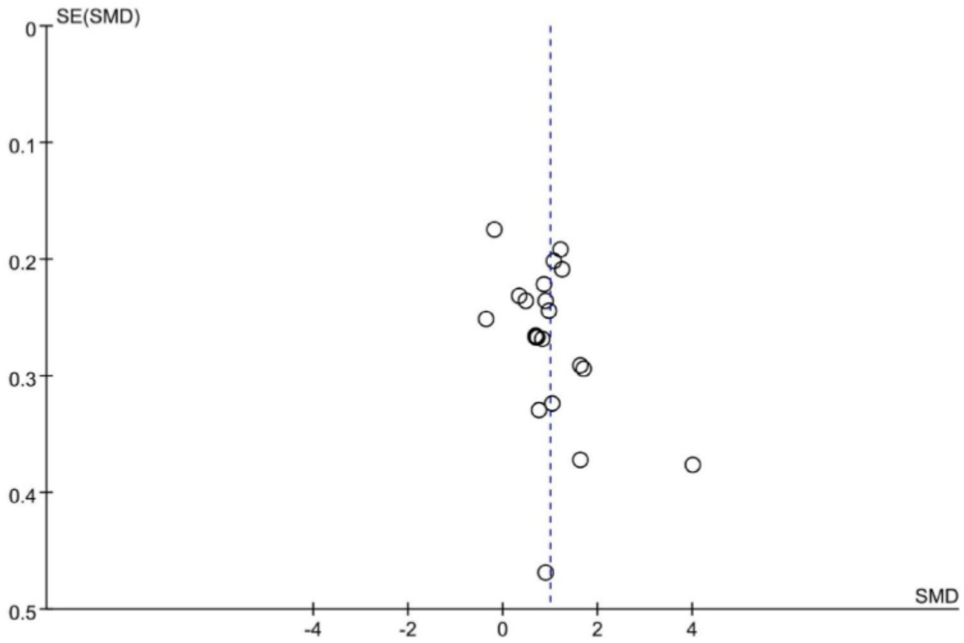

Fig. 3 Funnel plot showing no significant publication bias. *Note*: *SE* standard error, *SMD* standardized mean difference

Moderator analysis

As a result of the high heterogeneity among studies ($I^2 = 88\%$, $p < 0.00001$), the random-effects model was used for moderator analysis to explore the possible causes of heterogeneity and examine the influence of moderator factor variables. Data from the 21 included studies were extracted and coded for the three categories, with eight variables as possible moderators. It should be noted that a few studies were excluded from the moderator analysis because they did not provide sufficient information on the corresponding potential moderator variables (Shi et al., 2020a). Additionally, as noted by Means et al. (2013), the identified variable has at least two contrasting subsets, with each subset containing six or more study effects, so that the moderator variable could be constructed. Hence, the division of the subsets and the determination of the number of subsets regarding an identified moderator variable largely depended upon the number of studies to be included in each subset.

Instructional experiences

Table 4 shows the variation in effectiveness associated with three variables from the instructional experience category. The pedagogical approach, treatment duration, and pattern of participation were analyzed as moderator variables. Here, the pedagogical approach is divided into two types: collaborative and independent learning. The results of the

Table 4 Tests of instructional experiences as moderator variables

Variable	*N*	SMD	95% CI		*Z*-value	I^2 (%)	*p* value
			LL	UL			
Pedagogical approach[a]						0	0.89
Collaborative	6	0.74	0.26	1.22	3.05**		
Independent	11	0.78	0.51	1.04	5.74***		
Treatment duration[a]						0	0.70
≤ One month	7	1.14	0.31	1.98	2.69**		
> One month	11	0.97	0.64	1.30	5.76***		
Pattern of participation						0	0.67
SG	15	1.04	0.59	1.49	4.54***		
SG & TRP	6	0.93	0.70	1.16	7.98***		

N number of studies, *SMD* standardized mean difference, *95% CI* 95% confidence interval, *LL* lower limit, *UL* upper limit, *SG* student-generated, *TRP* teacher/researcher provided

[a]Moderator analysis excluded several studies because they did not report information about this feature

$^{**}p < 0.01$, $^{***}p < 0.001$

moderator analysis indicated that the pedagogical approach was not a significant moderator variable ($I^2 = 0\%$, $p > 0.05$). Coding for treatment duration was relatively coarse (not more than one month vs. more than one month), and the results showed that treatment duration was not a significant moderator variable ($I^2 = 0\%$, $p > 0.05$).

To examine the influence of mind mapping-based instruction on students with different participation levels, patterns of participation were analyzed as a moderator variable. In this study, only two subsets were identified: SG and SG & TRP. The results showed that the pattern of participation was not a significant moderator variable ($I^2 = 0$, $p > 0.05$).

Study condition

Table 5 shows the results of the moderator analysis on the category study condition. Three variables, namely, year of publication, subject matter, and educational level, were tested as moderator variables. The last few years have witnessed an obvious increase in the number of empirical studies of mind mapping. Years of publication were divided into two subsets, with the contrasting groups being studies published from 2010 to 2016 and those published from 2017 to 2019, which produced a numerical balance between the two subsets. The results showed that the year of publication was not a significant moderator variable ($I^2 = 46.7\%$, $p > 0.05$).

To establish whether mind mapping-based instruction has better effects in specific subjects relative to others, the subject matter of the included studies was divided into three: English, STEM (mathematics, science, technology, etc.), and other (medicine, health education, history, etc.). Subject matter was a significant moderator variable ($I^2 = 71.3\%$, $p < 0.05$).

Educational level was analyzed as a moderator variable to investigate the influence of mind mapping-based instruction on students with different education levels. Because of the limited number of studies that involved different levels of education, the educational level was divided into two subsets: K-12 education and higher education. Educational level was found to be a significant moderator variable ($I^2 = 84.8\%$, $p < 0.05$).

Table 5 Tests of study conditions as moderator variables

Variable	*N*	SMD	95% CI		*Z*-value	I^2 (%)	*p* value
			LL	UL			
Year of publication						46.7	0.17
2010–2016	8	0.74	0.30	1.19	3.30**		
2017–2019	13	1.16	0.76	1.57	5.65***		
Subject matter						71.3	0.03*
STEM	6	1.27	1.04	1.49	10.99***		
English	7	0.82	0.56	1.07	6.31***		
Other	8	0.90	0.20	1.60	2.53**		
Educational level						84.8	0.01*
K-12 education	12	1.30	0.88	1.71	6.15***		
Higher education	9	0.57	0.21	0.94	3.07**		

N number of studies, *SMD* standardized mean difference, *95% CI* 95% confidence interval, *LL* lower limit, *UL* upper limit

$^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Table 6 Tests of research methodology as moderator variables

Variable	*N*	SMD	95% CI		*Z*-value	I^2 (%)	*p*-value
			LL	UL			
Study design						70.3	0.07
RAC	6	0.67	0.35	0.98	4.12***		
QED	15	1.14	0.74	1.55	5.57***		
Sample size						0	0.44
<80	12	0.88	0.54	1.22	5.07***		
≥ 80	9	1.14	0.58	1.69	4.01***		

N number of studies, *SMD* standardized mean difference, *95% CI* 95% confidence interval, *LL* lower limit, *UL* upper limit, *RAC* random assignment control, *QED* quasi-experiment design

$^{***}p < 0.001$

Research methodology

For the research methodology category, study design and sample size were tested as moderator variables, as shown in Table 6. The influence of the study sample size was examined by dividing studies into two subsets: random assignment control and quasi-experimental design. Study design was not found to be a significant moderator variable ($I^2 = 70.3\%$, $p > 0.05$).

Sample sizes were divided into two subsets: studies with less than 80 students and those with not less than 80 students. The results showed that the sample size ($I^2 = 0$, $p > 0.05$) was not a significant moderator variable.

Discussion

In this meta-analysis, 21 peer-reviewed journal articles were selected and analyzed. The results and effect sizes extracted from the selected studies were sufficient to show that mind mapping-based instruction is more effective than traditional classroom instruction methods for improving students' cognitive learning outcomes. This result is consistent with the results of previous studies that stated that mind mapping-based instruction has a more positive impact on students' cognitive learning outcomes in formal learning environments (cf. e.g., Li et al., 2018). This study was conducted to provide greater clarity on the topic of mind mapping-based instruction, and we believe that our results provide the broadest synthesis of evidence describing the influence of mind mapping-based instruction toward students' cognitive learning outcomes.

Using a homogeneity test of the effectiveness of mind mapping-based instruction, significant variability was found in the effect sizes for different studies, which indicated that the identification of moderator variables could explain differences in students' cognitive learning outcomes between mind mapping-based instruction and traditional instruction. This study tested eight moderator variables in three aspects: instructional experience, study conditions, and research methodology. The analysis of moderator variables found two moderators (subject matter and educational level) that were both significant at the level of $p < 0.05$.

The influence of the moderator variable on the pedagogical approach (independent learning vs. collaborative learning) in mind mapping-based instruction showed that the pedagogical approach was not a significant moderator variable. This result was not consistent with the findings of some similar studies, such as a meta-analysis of flipped classroom-based instruction (Shi et al., 2020a) or a meta-analysis on augmented reality in education (Garzón et al., 2020). Both of those studies found that the pedagogical approach was a moderator variable for the effect size of their respective subjects. Nevertheless, mind mapping-based instruction was performed using two pedagogical approaches: collaborative learning (SMD = 0.74) and independent learning (SMD = 0.78), and both showed a positive impact on students' cognitive learning outcomes.

Another variable in the instructional experience category is treatment duration, which was not a significant moderator variable in this meta-analysis. In fact, the treatment duration for the included studies varied from 205 min to one year. Dividing these studies into different subsets with single or multiple cut-off points was difficult. According to Means et al. (2013), one month is an appropriate cut-off point. Using this guideline, we did not find that the treatment duration significantly influenced the effect size of mind mapping-based instruction. This finding is consistent with similar studies conducted by Means et al. (2013), Shi et al. (2020a), and (2020b). All of those studies found that treatment duration produced no significant difference in the effectiveness of blended/flipped/technology-enabled active learning on students' cognitive learning outcomes. It should be noted that the effect size of treatment duration of not more than one month (SMD = 1.14) was slightly higher than that of more than one month (SMD = 0.97), which is consistent with the findings of Li et al. (2018), who showed that treatment durations within one month had the largest effect size in a meta-analysis assessing the effectiveness of mind mapping on student academic performance.

Analysis of the moderator variables on the participation level of students and instructors indicated that it was not a significant moderator of effects. This finding is inconsistent with the results of Li et al. (2018), who found that instruction with mind mapping generated by the teacher/researcher and students had a significantly larger effect size on student academic performance in comparison with instruction with mind mapping generated by the teacher/researcher or students alone. These mixed results indicate that whether the teacher/researcher should provide mind mapping for students or generate the mind mapping with students together remains to be discussed. To this end, the cooperative manner arising between the teacher/researcher and students needs further investigation to improve the effectiveness of mind mapping-based instruction.

The year of publication was not found not to be a significant moderator variable in the meta-analysis of mind mapping-based instruction. This result is consistent with the studies conducted by Means et al. (2013) and Shi et al. (2020a); neither of those studies found that the year of publication was a significant moderator in the meta-analyses concerning blending learning or flipping learning. It should be noted that the meta-analysis indicated that the effect size of the studies published from 2017 to 2019 (SMD = 1.16) is slightly higher than that of the studies published from 2010 to 2016 (SMD = 0.74). This is consistent with the results of a similar meta-analysis study on technology-enabled active learning (Shi et al., 2020b), which showed that the effect size of studies published after 2013 (SMD = 0.70) is slightly higher than that of studies published between 2006 and 2012 (SMD = 0.42). It is generally accepted that thanks to the rapid development of ICTs, more advanced instructional technologies and complicated instructional practices have been introduced into the educational environments in recent years. Hence, there are reasons to believe that more recent studies regarding mind mapping-based instruction would produce more positive effects on student learning outcomes.

There are significant differences among the subjects involved in the meta-analysis of mind mapping-based instruction, which is consistent with the results of similar meta-analysis studies (Balta et al., 2017; Strelan et al., 2020). Additionally, STEM disciplines have had the largest effect size in moderating the effect of mind mapping-based instruction, which has suggested that mind mapping-based instruction is more effective in the STEM disciplines. This finding is consistent with the results of similar meta-analysis studies conducted by Vo et al. (2017), which found a significantly higher mean effect size in STEM disciplines relative to that in non-STEM disciplines regarding the effects of blended learning on learning achievement in college students. The STEM disciplines have attracted significant attention recently. Freeman et al. (2014) conducted a meta-analysis that was focused on the effect of active learning on student performance in STEM disciplines. However, other similar meta-analyses, such as those conducted by Hew and Lo (2018) and Shi et al. (2020b), have found that subject matter was not significant in moderating the effects of flipped learning or technology-enabled active learning. These mixed results indicate a research gap for future studies to fill to increase the effectiveness of mind mapping-based instruction on various subjects.

Studies are categorized by educational level and are simply divided into K-12 education (including elementary education, junior high school education, and high school education) and higher education. The results of moderator analysis showed that educational level was a significant moderator variable, which indicated that mind mapping was more effective for K-12 education. This finding is partly consistent with the results of Liu et al. (2014), who found the largest effect size in primary school, among middle school, senior high school, and college. One reason for this might be that students at lower educational levels are more susceptible to becoming affected by mind mapping. Another meta-analytic study conducted by Li et al. (2018) showed that mind mapping-based instruction had a larger effect size in senior high school education than in higher education. As Davies (2011) pointed out, mind mapping could be useful for assisting students to recollect items in an examination (or a presentation), but it is of limited assistance in dealing with more complex relationships. It is generally believed that learning materials and learning tasks in higher education are more complex than those of K-12 education, which might explain why mind mapping-based instruction has a larger effect size in K-12 education than in higher education. Additionally, differences regarding the effects of mind mapping-based instruction on student learning achievement also exist within K-12 education (Li et al., 2018; Liu et al., 2014). We did not split up K-12 education into more specific subsets (such as elementary education, junior high school education, and senior high school education), because the number of studies in each specific subset did not meet the minimum quantity requirement for moderator analysis.

The examination of the influence of research methodology variables showed that effect sizes did not vary significantly with study design. This is consistent with the results of several similar studies (e.g., Hew & Lo, 2018; Means et al., 2013; Shi et al., 2020a). Generally, the mind mapping-based instruction produced better students' cognitive learning outcomes than traditional instruction in studies that either used a study design of random assignment control ($p < 0.001$) or a quasi-experimental design ($p < 0.001$). It can be concluded that mind mapping-based instruction has enabled more effective pedagogical approaches and instructional designs for students, resulting in improved efficiency of instruction in recent years.

Moderator analysis in research methodology variables showed that the sample size was not a significant moderator variable for the meta-analysis. This is consistent with the results of similar meta-analyses of peer instruction (Balta et al., 2017) and online learning (Means et al., 2013). Neither of those studies identified that sample size was a significant moderator.

Conclusion

Recently, as educational technology has developed, researchers and educators have begun to use mind mapping tools to achieve education-related purposes. Mind mapping tools take advantage of a variety of diagrammatic relationships, and pictures and structural diagrams are often considered easier to understand than written or verbal descriptions (Davies, 2011). Therefore, mind mapping-based instruction has been widely utilized and studied among students at different educational levels and across a wide range of subjects. This study synthesized the findings of 21 high-quality peer-reviewed empirical articles to provide clarification of the influence of mind mapping-based instruction on students' cognitive learning outcomes. Generally, meta-analyses of the relevant literature showed that mind mapping-based instruction significantly improved students' cognitive learning outcomes in relation to traditional instruction. Moreover, mind mapping-based instruction has proven more effective when it was implemented in STEM subjects and K-12 education.

However, this meta-analysis is subject to research limitations. First, some research articles were not included in the study because of the insufficient information they provided. Only two rough divisions between K-12 education and higher education have been made with respect to the education level of students. Future studies are encouraged to report more detailed information to support moderator variable analysis, enabling the expansion of knowledge in the field through future meta-analytic research on mind mapping. Moreover, as the effects of mind mapping-based instruction on students' cognitive learning outcomes vary among different educational levels, future studies should be conducted to explore the possible mechanisms for the different effects and provide in-depth implications for educators and researchers. Second, this study only examined the topic in relation to cognitive learning, without considering other learning perspectives, such as affective, attitude, or behavioral skill outcomes. Third, because of the limited number of studies examined, we did not conduct a more detailed analysis of the moderator variable analysis, splitting up the moderators into more subsets, such as the educational level and subject matter. Thus, more empirical studies should be conducted to examine the effects of mind mapping on student learning achievement from different educational levels and varied subjects.

Because of the significance of mind mapping-based instruction in education, the quality of studies of it is expected to increase. This study provides an initial, multidisciplinary snapshot of evidence suggesting that researchers, practitioners, and policy-makers should continue to study and support mind mapping-based instruction, as it has a positive influence on students' cognitive learning outcomes. However, the topic of instructional models is dynamic and multifaceted, so it is important and necessary to regularly investigate the results of studies in subject-specific and learning model-specific findings and to maintain an objective and systematic understanding of the effects of mind mapping-based instruction on student learning outcomes.

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Declarations

Conflict of interest The authors declare that they have no conflict interest.

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