Metacognition in Science Learning: Bibliometric Analysis of Last Two Decades

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Abstract

The main objective of this study was to map (1) the research of metacognition in science learning; (2) learning interventions used and metacognition’s key components that learned, integrated, and investigated; and (3) future research recommendations of metacognition research in science learning. We analyzed 438 scientific documents published in journals and books indexed in the Scopus database using VOSviewer software to visualize research trends and main keywords investigated of metacognition in science learning. The research findings show that research in the field of metacognition in science learning through the metacognition as attribution that integrated into learning interventions and as a learning outcome has increased in the last two decades. Scientific concepts understanding, critical thinking skills, motivation, and attention are the main goals in metacognition research. Inquiry-based learning, such as problem-based learning, is the most frequently used intervention to teach students metacognition. The research gaps found are (1) the cognitive regulations are the most investigated aspect, while cognitive aspects such as declarative knowledge, procedural knowledge, and conditional knowledge have not been widely investigated in science learning; (2) metacognition research on college students has a high frequency compared to school students; and (3) the integration of metacognition in online learning is still less investigated, this is indicated by the recommendations of several research results that encourage the integration of self-regulated learning into online learning.

Keywords: metacognition; science learning; research trends; bibliometric analysis


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INTRODUCTION

Thinking about thinking (Lai, 2011) or the ability to control and monitor the cognitive process (Flavell, 1979; Schraw et al., 2012) was the definition of metacognition that is usually found in many pieces of literature. The concept of metacognition has lately been considered an essential component in scientific research (Negretti, 2021), including in science learning contexts (Zohar & Barzilai, 2013). Metacognition potentially promotes students to achieve good conceptual understanding and learning strategy (Dori et al., 2018), facilitate students to applicate science concept in a real context (Fleur, 2021), increases student's conceptual mastery (Muhali et al., 2019), and monitoring information needed in the text (Beaufort, 2012). Furthermore, metacognition is the key to understanding the ideas of science concepts (Vrieling et al., 2018), helping students independently regulate their knowledge to
create or evaluate the decisions accurately (Boud & Soler, 2016; Tai et al., 2018). The result of previous research also showed that metacognition encourages active engagement in learning (Binali et al., 2021), positively correlate with learning interest (Labroo & Pocheptsova, 2016; Tsai et al., 2018), increase willingness to learn (McDowell, 2019), and is considered as the essential provision to face the real work demands (Cervin-Ellqvist et al., 2021).

Metacognition is defined as cognitive interaction with others or the environment (Flavell, 1979). Metacognition is high-level cognition (Anderson & Krathwohl, 2001) demonstrated through monitoring and regulatory strategies (Kluwe, 1982). Further explained, metacognition emphasizes the process of knowledge construction based on the learning objectives that have been formulated, accompanied by monitoring, regulation, control of cognition, motivation, and behavior (Pintrich, 2000) according to the objectives and the learning environment context (Asy’ari et al., 2019; Suhirman et al., 2021). Metacognition involves cognition and awareness/cognition regulation (Schraw et al., 2006; Sperling et al., 2004; Veenman, 2012) to select the best strategy in problem-solving (Bol & Garner, 2011; McCormick, 2003; Papaleontiou-Louca, 2008). The statement shows two main components of metacognition, namely metacognitive knowledge and metacognitive awareness. Metacognitive knowledge is related to knowledge about thinking processes from interactions with the environment (Flavell, 1979; Schunk, 2012; Zimmerman & Moylan, 2009). It consisted of declarative, procedural, and conditional knowledge (Hoy, 2013; Schraw et al., 2006; Zohar & David, 2008). Metacognitive awareness is related to knowledge control and motivational aspects (Krathwohl, 2002) in learning and problem-solving (Kaberman & Dori, 2009), that are classified into eight sub-components: declarative knowledge, procedural knowledge, conditional knowledge, planning, information management, monitoring, debugging, and evaluation (Schraw et al., 2006).

Metacognition is very important in science learning (Lavi et al., 2021; Negretti, 2021), which involves evaluating scientific and technological knowledge from the point of view of products, processes, and skills (Hernández-Ramos et al., 2021). Science learning aims to improve scientific literacy (Taber, 2015) and encourage activities that enable students to think like scientists (Ash, 2000; Dori et al., 2018) through laboratory activities (Crawford et al., 2005; Crawford & Capps, 2018) and the integration of authentic phenomena to find the relevance of knowledge with natural/environmental phenomena (Dunlosky & Rawson, 2015). The learning orientation as described above is allegedly able to teach students to know how to learn (Arends, 2012), improve metacognitive skills (Avargil et al., 2018), and so far is considered essential and demand for 21st-century science learning (Kober, 2015). However, the differences of opinion regarding the definition and main components of metacognition (Veenman, 2012) cause differences in the integration and trends of metacognition research in science teaching (Efklides, 2008; Peña-Ayala & Cárdenas, 2015; Veenman, 2012).

Systematic and bibliometric reviews are often used to identify research trends (H. Chen & Ho, 2015). The study aims to clarify the crucial components, trends, and even the novelty of the variables intended for further research (Yang et al., 2017). In the last two decades, five systematic review articles were found in the Scopus database, in which four systematic studies on metacognition explicitly linked to science learning in scientific journals and book chapters (Georghiades, 2004; Thomas, 2012; Veenman, 2012; Zohar & Barzilai, 2013) and one systematic study of
metacognition in the field of psychology in five years (2003-2007) (Dinsmore et al., 2008). Systematic review by Georghiades (2004) describe and listing different terms that associated with metacognition over the past three decades. The paper also addressed the metacognition relation with general thinking skills and synopsize future metacognition’s research outcomes in general and science education. A more explicit description is found in the papers of Thomas (2012) and Veenman (2012) related to the important components and directions of metacognition development in science learning. Unfortunately, the criteria and database sources for the articles studied in this paper are not explained. Furthermore, a systematic review by Zohar and Barzlilai (2013) identified metacognitive research in the last ten years recorded in the ERIC database. The results of this study describe trends, conceptualization of metacognition in science learning, and characteristics of metacognition learning designs. The description shows that research based on systematic/bibliometric reviews on metacognition in science learning is still rare. This article aims to identify the components of metacognition that are often used as research variables in science learning in the last two decades. Learning interventions, the main instrument used to identify metacognition in science learning that not describe in the previous articles, are also described in this article so that recommendations for research and science learning oriented to metacognition can be formulated.

METHOD

This study uses a bibliometric analysis guide (Dong et al., 2012; Kulakli & Osmanaj, 2020) using the Scopus database as a data source with the consideration that Scopus is globally used as a reference for the quality of scientific articles. The Scopus database combines abstracts and database quotes from related scientific literature from various disciplines. It is very relevant to be used as a data source in this research. In addition, features that are easy to find experts, data, metrics, and visualization of research priority directions/trends in the Scopus database are also helpful in conducting bibliometric research in this article. This research was conducted by including the term “metacognition in science learning”; on the label option “Article title, Keywords, and Abstract”; range limited from 2000-2021, and the “Social Science” field (see Figure 1). The document search process was carried out from 20-30 December 2021.

The initial search found 35,307 documents published from 1978 to 2022. After the limitation, 438 documents of metacognition in science learning were published from 2000 to 2021. The results are documented in (.csv) and (.ris) files. The files were processed using Microsoft Excel and VOSviewer to visualize research trends (van Eck & Waltman, 2020) of metacognition in science learning. The analysis to identify publication trends and research trends in terms of metacognition in science learning in the last two decades was conducted using VOSviewer. The keywords’ co-occurrence in VOSviewer software was carried out to multidimensional scaling.
RESULTS AND DISCUSSION

Research Trends of Metacognition in Science Education

The publication trend of metacognitive research in science learning is increasing yearly (see Figure 2), showing the importance of metacognition to be taught practically in science learning. Changes in the 21st-century learning paradigm (Haug & Mork, 2021) that emphasizes the active involvement of students in learning and knowledge construction to strengthen conceptual understanding (de Jong, 2019) and learning orientation to facilitate students' higher-order thinking skills (Fischer et al., 2014; Porter & Peters-Burton, 2021) including metacognitive abilities (Perry et al., 2019) have led to an increase in research and learning trends in recent years. In line with the statement, constructivists believe that students should be taught how to learn (Ausubel, 1968; Barrow, 2006; Sternberg et al., 2008; Vygotsky, 1981; Zimmerman & Moylan, 2009) in various contexts (Peters & Kitsantas, 2010) including science (Burton, 2013). Integrating the principle of self-regulation (cognitive regulation aspect) in learning helps achieve better cognitive achievement (Liu et al., 2021).

![Figure 2. Publication trends of metacognition on science learning](image-url)
science applications) (National Research Council, 2012). Content knowledge refers to the learning materials and how students learn these materials (Haug & Mork, 2021). Science learning materials do not only refer to conceptual knowledge (Muhali et al., 2021), but understanding science as a process and practice and how scientific knowledge is developed in inquiry activities are also included in science learning materials (Morrison, 2013). At that point, metacognition, which is claimed to help students adapt to the environment (Ouyang et al., 2020), is very important to learn.

**Learning Interventions and Key Components of Metacognitive Research**

Various learning approaches have been used as interventions to train students' metacognition. An inquiry-based approach was the most frequently used intervention in teaching metacognition (Figure 3). The importance of metacognition for students encourages many experts to formulate relevant learning schemes for this purpose. Schoenfeld (1983), with a problem-solving scheme, includes reading, analysis, exploration, planning, implementation, and verification activities that are based on belief systems, social cognition, and metacognition, developed to drive academic performance to solve problems faced. Furthermore, Schoenfeld (2016) explains that three levels of knowledge and needs must be met to achieve these goals, including resources of knowledge, strategic mastery as knowledge controlling and monitoring, and belief systems. Along the way, Kroll (1988) expanded the problem-solving scheme (Schoenfeld, 1983) in cooperative problem-solving to clarify monitoring and problem-solving procedures in groups through orientation, organization, implementation, and verification steps.

On the other hand, the cognitive-metacognitive scheme consists of phases (1) orientation (strategy understanding, analysis of information and conditions, assessment of familiarity with an initial task and its presentation, the assessment of the difficulty of the problem and hope for success, beginning with students trying to become accustomed to it with problem situations); (2) organization (identification of main goals and objectives, general planning, and specific planning to complete the general plan); (3) execution (achievement of local actions, monitoring the progress of global and local plans, and assessing decisions in the form of performance appraisals such as accuracy and fluency); and (4) verification (evaluation of decisions and results of executed plans). The scheme is a metacognition teaching intervention based on a meta-component integrated problem-solving scheme such as planning, monitoring, and evaluating the problem-solving process; integrated into the steps of (1) recognizing the problem, (2) describing the state of the problem, (3) preparing mental and physical needs to solve problems, (4) determining how to collect information, (5) preparing problem-solving steps, (6) combines these steps with appropriate strategies, (7) monitors the progress of problem-solving during the process, and (8) evaluates solutions when problems are resolved (Sternberg, 1982).

The intervention of teaching metacognition by inserting attribution reflection on the learning steps has also been formulated, such as the problem-solving model by Yimer and Ellerton (2010) with steps engagement, transformation-formulation, implementation, evaluation, and internalization, and Muhali et al. (2019) with steps of orientation reflection, organizational reflection, execution reflection, and verification reflection. The metacognition teaching intervention scheme that has been described epistemologically refers to inquiry-based intervention (Figure 3). Inquiry-based was the common learning intervention used in the science classroom to facilitate participants' metacognition. The problem-based learning (PBL) model is one of the
inquiry-based learning that is student-oriented and in accordance with the principles of science as a process (Crippen et al., 2016). Not only metacognition, but PBL is also empirically found to be able to train students' active collaboration and communication skills (Kokotsaki et al., 2016). The results showed that problem-solving and critical thinking skills could be improved through the implementation of the PBL model (Jerome et al., 2017).

Previous research found that authentic problem-solving-oriented learning had a significant impact on students' thinking skills (Fini et al., 2018). The PBL model requires students to engage in complex, challenging, and authentic problem solving (Masino & Niño-Zarazúa, 2016). The description indicates that students have the potential to be studied intensively in formulating strategies for solving problems encountered (procedural knowledge). In line with this statement, inquiry-based interventions add to students' learning experience and collaboration during learning (Noguera et al., 2018; Rambocas & Sastry, 2017).

In addition to the advantages of using inquiry-oriented learning interventions, there are several weaknesses identified in previous empirical research, such as not having a significant impact on the metacognitive awareness component (debugging) (Tosun & Senocak, 2013) and not always being suitable for certain materials (Grossman et al., 2019). Some research results recommend teachers/lecturers pay attention to students' understanding of learning objectives and have access to the materials needed to solve the problems being worked on (Eggen & Kauchak, 2012), emphasis on increasing scientific literacy (Li, 2021), assessment of learning performance using portfolio (Guo et al., 2020) and the integration of PBL in modern learning or online learning (Efstratia, 2014).

Various research results show the superiority of inquiry-based learning-oriented in developing students' knowledge and skills (Ralph, 2016). However, some students are reported to be unmotivated in group work (Guo et al., 2020). In contrast to the results of this study, Reis et al., (2017), who conducted bibliometric research, found that students' motivation, knowledge, and skills increased after learning. Apart from being allegedly a form of teaching that is very relevant to the principles of science as a process (Crippen et al., 2016) and has a positive impact on student learning outcomes in general (Fini et al., 2018). The implementation of inquiry-based learning is believed to help achieve cognitive learning outcomes and social skills (Ozdemir et al., 2015), which increases students' higher-order thinking skills (Prayoonsri et al., 2015). This opinion is in line with the statement that new skills in learning can be raised through collaborative activities (Miller & Krajcik, 2019). The description of this opinion is evident from the many research results that show positive impacts in science learning, such as a significant increase in learning outcomes (C.-H. Chen & Yang, 2019), critical thinking skills (Sasson et al., 2018), attitudes, and motivation (Hasni et al., 2016; Kortam et al., 2018).
Self-regulation, attention, metacognitive strategy, monitoring, regulation, belief system, behavior, emotion, metacognitive process, and memory were the most metacognitive dimensions investigated in science learning (Figure 4). In line with the research results, self-regulation is a core concept in understanding aspects of knowledge, motivation, emotions in learning (Panadero & Järvelä, 2015). The results show that self-regulation plays an essential role in monitoring knowledge and problem-solving strategies (Binali et al., 2021).

The composition of metacognition often differs between knowledge and metacognitive skills (Brown, 1978; Flavell, 1979). These differences lead to the process of self-regulation (Veenman, 2012). In line with this opinion, Schraw et al. (2012) mention knowledge of cognition and regulation of cognition as a core component of metacognition. On the other hand, Efklides and Misailidi (2010) explain that metacognition is obtained through affection related to assessment, estimation, and
thinking that is aware of all processes carried out during completing a task that is shown through liking, interest/attention, curiosity, dissatisfaction, and desire to start.

Metacognitive knowledge emphasizes declarative knowledge related to the individual's relationship to the task and the characteristics of the strategy used to complete the task at hand (Flavell, 1979). Another component of metacognitive knowledge is conditional knowledge, which determines when strategies to solve problems can be used to achieve goals. Metacognition knowledge does not guarantee the strategy's implementation, so procedural knowledge is related to how the strategy can be implemented.

Metacognitive knowledge and metacognitive skills possessed are then regulated. The regulation of knowledge and awareness of metacognition in question is shown through attitudes that have several components, namely: (1) planning that emphasizes student attitudes in determining the goals to be achieved and the willingness of initial sources to learn, (2) information management, namely strategies used to process information more efficiently, (3) monitoring on continuous assessment related to learning or strategies used, (4) debugging namely strategies used during learning to improve understanding and performance errors, and (5) evaluation, namely the analysis of the effectiveness of performance and strategies after learning (Schraw et al., 2012). The component of cognitive regulation is based on the constructivist opinion that students are not enough to know but must know how to apply it (Loughran, 2002).

Future Recommendation of Metacognition Research in Science Learning

Figure 3 shows four clusters of metacognition research in science learning. Cluster 1 (red) is related to metacognitive components that are integrated and or identified as cognitive and affective products in science teachings such as self-regulation, explanation, regulation, critical thinking, attention, communication, memory, and conceptual understanding through collaboration-based learning, inquiry, case studies, as well as projects in the perspective of scientific issues in the literature and the real world. Cluster 2 (green) is related to methods used of metacognition in science learning research. Recommendations for future research related to online learning (integrated technology) based on self-regulated learning are also identified in this cluster. Cluster 3 (blue) is related to the instruments and dimensions of metacognition investigated in the study. Questionnaires were identified as the most frequently used instruments in metacognition research to identify metacognitive dimensions such as metacognitive strategies, regulation, monitoring, reading and writing strategies, and emotions. While cluster 4 (yellow) indicates the subject and object of metacognition research. University students are often used as research subjects, and topics in science, technology, engineering, and mathematics (STEM) become objects in metacognitive research.
Integration of technology based on self-regulated learning (SRL) was the important recommendation of future research on metacognition in science learning. There are two possible reasons for this recommendation to appear. First, the COVID-19 pandemic caused the demand for online learning to increase. Unfortunately, the application of online learning is still heavily constrained by the low level of digital literacy (Egorov et al., 2021), which can be seen from the plagiarism of student assignments, not being on time, and difficulties in conducting online learning (Aikina & Bolsunovskaya, 2020), became the common problem encountered in online learning, where students' affective aspects tend to decrease, such as motivation (Goh et al., 2014) due to inadequate learning designs (Sole & Anggraeni, 2018). The results of this study are not in line with the expectation that online learning should provide the same benefits and motivation to students as face-to-face learning on aspects of learning processes and products (Lynch, 2020).

Second, many empirical studies show different results. Online learning has a positive impact on motivation, digital competence, collaboration, and learning strategies (Viegas et al., 2012) and significantly improves student performance (Bouroumi & Fajr, 2014). However, it should be considered that metacognition learning in science learning is often taught using an inquiry-based approach such as the PBL model. In problem-based learning, students are given authentic problems (Birgili, 2015) which are the hallmark of PBL (Masino & Niño-Zarazúa, 2016). However, the results of empirical research found that PBL model-based learning requires students to have adequate initial conceptual knowledge to be able to be actively involved in PBL model activities (Muhali et al., 2019) so that the potential for difficulties in the PBL model learning process and the low quality of problem-solving strategy formulation if you do not have an adequate understanding of the concept. Furthermore, the PBL model does not have a significant impact on the component of metacognition awareness (debugging) (Tosun & Senocak, 2013), paying attention to conceptual understanding on materials related to the problems at hand (Eggen & Kauchak, 2012), emphasizing on increasing scientific literacy (Li, 2021), assessment of learning performance using portfolio (Guo et al., 2020) and integration of PBL in modern (hybrid) learning (Efstratia, 2014).
CONCLUSION

Based on the data visualization of the publication of metacognition research results in science learning, it was found that the publication of research publications has increased over the last two decades. The regulation of cognition (metacognition awareness) is the most studied, such as self-regulation, attention, metacognitive strategy, monitoring, and regulation. The most frequently used instrument also shows this is the questionnaire (Figure 3). Metacognition Awareness Inventory (MAI) (Schraw & Dennison, 1994) is an instrument in the form of a questionnaire commonly used to investigate or take inventory of metacognitive awareness.

RECOMMENDATION

Metacognition cognitive aspects have not been widely investigated in science learning, so it need to consider for future research. Furthermore, most metacognition investigations and teaching are conducted at the university level using inquiry-based learning. The integration of metacognition in online learning, investigation of aspects of metacognitive knowledge, and implementation in schools need to be carried out for future research.

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DECLARATION OF INTEREST

The author/s declare no conflict of interest.

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