Jurnal Penelitian dan Pengkajian Ilmu Pendidikan: e-Saintika
https://journal-center.litpam.com/index.php/e-Saintika/index
March 2022 Vol. 6, No. 1
e-ISSN: 2615-6881
pp. 43-60

Metacognition in Science Learning: Bibliometric Analysis of Last Two Decades

***Mohd Dzul Hakim Wirzal, Nur Syakinah Abdul Halim, Nik Abdul Hadi Md Nordin, Mohamad Azmi Bustam**
Chemical Engineering Department, Universiti Teknologi PETRONAS, 32610 Seri Iskandar, Perak, Malaysia

*Corresponding Author e-mail: mdzulhakim.wirzal@utp.edu.my

Received: March 2022; Revised: March 2022; Published: March 2022

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

How to Cite: Wirzal, M. D. H., Halim, N. S. A., Md Nordin, N. A. H., & Bustam, M. A. (2022). Metacognition in Science Learning: Bibliometric Analysis of Last Two Decades. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, *6*(1), 43–60. https://doi.org/10.36312/esaintika.v6i1.665

https://doi.org/10.36312/esaintika.v6i1.665

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 Barzilai (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.

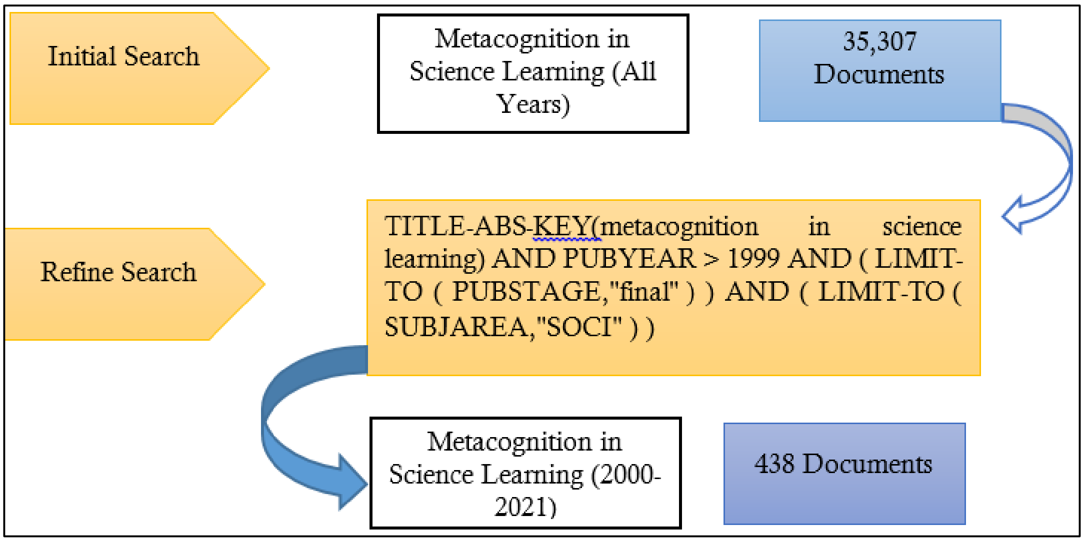

Figure 1. Search flow

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).

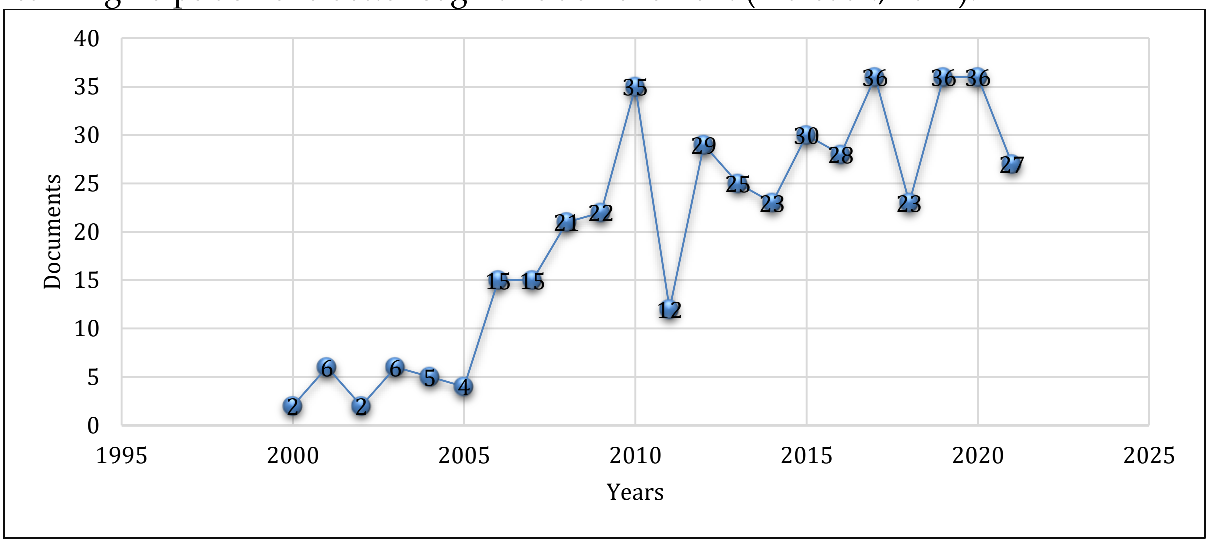

Figure 2. Publication trends of metacognition on science learning

The increase of metacognition research is based on the school curriculum's learning demands that focus on strengthening content knowledge (literacy skills and 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. 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).

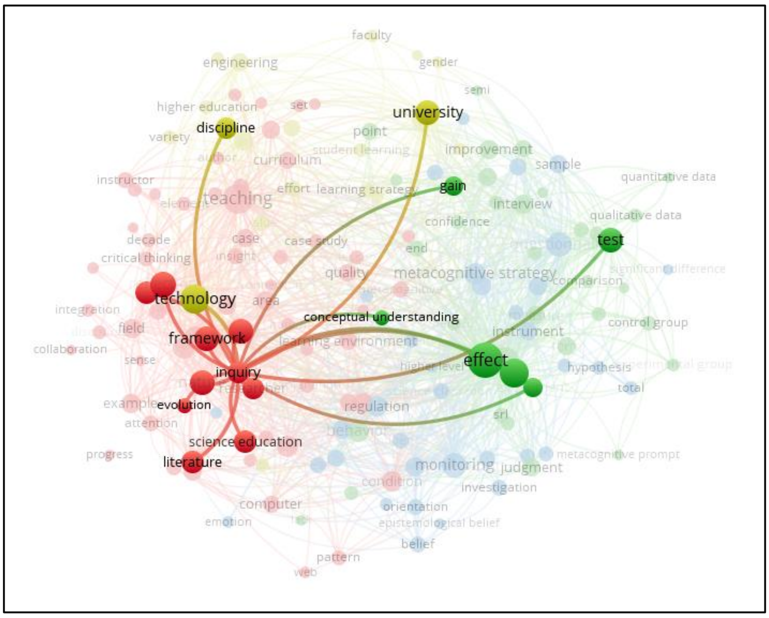

Figure 3. Methods of teaching metacognition in science class

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).

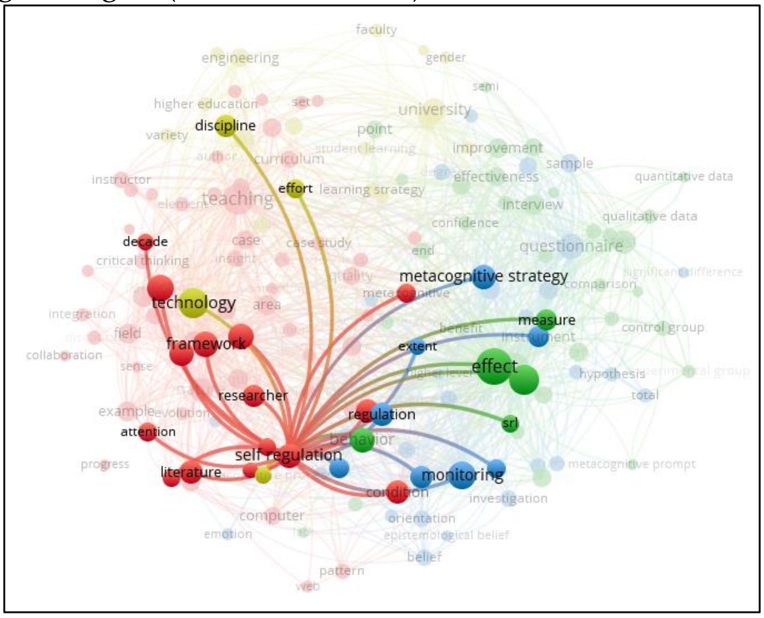

Figure 5. The most metacognitive dimensions investigated in science learning

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.

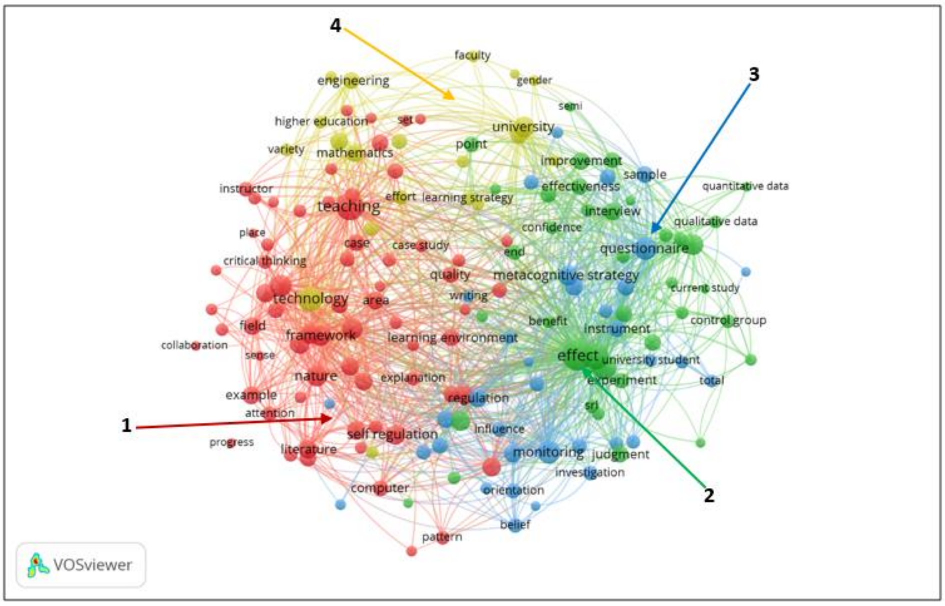

Figure 3. Metacognition research cluster in science learning

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), were become 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 (Bïrgili, 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).

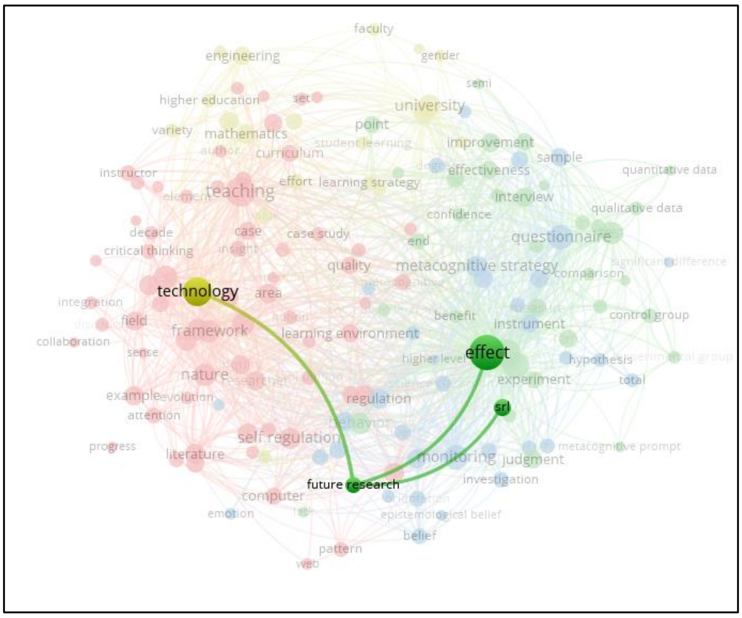

Figure 4. Future research recommendation on metacognition in learning

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.

ACKNOWLEDGMENT

This research received no specific grant from any funding agency in the public, commercial, or not for profit sectors.

DECLARATION OF INTEREST

The author/s declare no conflict of interest.

REFERENCES

Aikina, T. Y., & Bolsunovskaya, L. M. (2020). Moodle-Based Learning: Motivating and Demotivating Factors. *International Journal of Emerging Technologies in Learning (IJET)*, *15*(02), 239. https://doi.org/10.3991/ijet.v15i02.11297

Anderson, L. W., & Krathwohl, D. R. (Eds.). (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives* (Complete ed). Longman.

Arends, R. (2012). *Learning to teach* (9th ed). McGraw-Hill.

Ash, D. (2000). *The Process Skills of Inquiry*. *2*, 12.

Asy'ari, M., Ikhsan, M., & Muhali, M. (2019). The Effectiveness of Inquiry Learning Model in Improving Prospective Teachers' Metacognition Knowledge and Metacognition Awareness. *International Journal of Instruction*, *12*(2), 455–470. https://doi.org/10.29333/iji.2019.12229a

Ausubel, D. P. (1968). *Educational psychology: A cognitive view*. Holt, Rinehart and Winston.

Avargil, S., Lavi, R., & Dori, Y. J. (2018). Students' Metacognition and Metacognitive Strategies in Science Education. In Y. J. Dori, Z. R. Mevarech, & D. R. Baker (Eds.), *Cognition, Metacognition, and Culture in STEM Education* (Vol. 24, pp. 33–64). Springer International Publishing. https://doi.org/10.1007/978-3-319-66659-4_3

Barrow, L. H. (2006). A Brief History of Inquiry: From Dewey to Standards. *Journal of Science Teacher Education*, *17*(3), 265–278. https://doi.org/10.1007/s10972-006-9008-5

Beaufort. (2012). College writing and beyond: Five years later. *Composition Forum*, *26*, 1–13.

Binali, T., Tsai, C.-C., & Chang, H.-Y. (2021). University students' profiles of online learning and their relation to online metacognitive regulation and internet-specific epistemic justification. *Computers & Education*, *175*, 104315. https://doi.org/10.1016/j.compedu.2021.104315

Bïrgïlï, B. (2015). Creative and Critical Thinking Skills in Problem-based Learning Environments. *Journal of Gifted Education and Creativity*, *2*(2), 71–80.

Bol, L., & Garner, J. K. (2011). Challenges in supporting self-regulation in distance education environments. *Journal of Computing in Higher Education*, *23*(2–3), 104–123. https://doi.org/10.1007/s12528-011-9046-7

Boud, D., & Soler, R. (2016). Sustainable assessment revisited. *Assessment & Evaluation in Higher Education*, *41*(3), 400–413. https://doi.org/10.1080/02602938.2015.1018133

Bouroumi, A., & Fajr, R. (2014). Collaborative and Cooperative E-learning in Higher Education in Morocco: A Case Study. *International Journal of Emerging Technologies in Learning (IJET)*, *9*(1), 66. https://doi.org/10.3991/ijet.v9i1.3065

Brown, A. L. (1978). Knowing when, where, and how to remember: A problem of metacognition. In L. Glaser (Ed.), *Advances in instructional psychology* (pp. 367–406). Halsted Press.

Burton, E. P. (2013). Student work products as a teaching tool for nature of science pedagogical knowledge: A professional development project with in-service secondary science teachers. *Teaching and Teacher Education*, *29*, 156–166. https://doi.org/10.1016/j.tate.2012.09.005

Cervin-Ellqvist, M., Larsson, D., Adawi, T., Stöhr, C., & Negretti, R. (2021). Metacognitive illusion or self-regulated learning? Assessing engineering students' learning strategies against the backdrop of recent advances in cognitive science. *Higher Education*, *82*(3), 477–498. https://doi.org/10.1007/s10734-020-00635-x

Chen, C.-H., & Yang, Y.-C. (2019). Revisiting the effects of project-based learning on students' academic achievement: A meta-analysis investigating moderators.

Educational Research Review, *26*, 71–81. https://doi.org/10.1016/j.edurev.2018.11.001

Chen, H., & Ho, Y.-S. (2015). Highly cited articles in biomass research: A bibliometric analysis. *Renewable and Sustainable Energy Reviews*, *49*, 12–20. https://doi.org/10.1016/j.rser.2015.04.060

Crawford, B. A., & Capps, D. K. (2018). Teacher Cognition of Engaging Children in Scientific Practices. In Y. J. Dori, Z. R. Mevarech, & D. R. Baker (Eds.), *Cognition, Metacognition, and Culture in STEM Education* (Vol. 24, pp. 9–32). Springer International Publishing. https://doi.org/10.1007/978-3-319-66659-4_2

Crawford, B. A., Zembal-Saul, C., Munford, D., & Friedrichsen, P. (2005). Confronting prospective teachers' ideas of evolution and scientific inquiry using technology and inquiry-based tasks. *Journal of Research in Science Teaching*, *42*(6), 613–637. Scopus. https://doi.org/10.1002/tea.20070

Crippen, K. J., Wu, C. Y., Boyer, T., De Torres, T., Korolev, M., & Brucat, P. J. (2016). A pilot study of project-based learning in general chemistry for engineers: 123rd ASEE Annual Conference and Exposition. *2016 ASEE Annual Conference and Exposition*, *2016-June*. http://www.scopus.com/inward/record.url?scp=84983301348&partnerID=8YFLogxK

de Jong, T. (2019). Moving towards engaged learning in STEM domains; there is no simple answer, but clearly a road ahead. *Journal of Computer Assisted Learning*, *35*(2), 153–167. https://doi.org/10.1111/jcal.12337

Dinsmore, D. L., Alexander, P. A., & Loughlin, S. M. (2008). Focusing the Conceptual Lens on Metacognition, Self-regulation, and Self-regulated Learning. *Educational Psychology Review*, *20*(4), 391–409. https://doi.org/10.1007/s10648-008-9083-6

Dong, B., Xu, G., Luo, X., Cai, Y., & Gao, W. (2012). A bibliometric analysis of solar power research from 1991 to 2010. *Scientometrics*, *93*(3), 1101–1117. https://doi.org/10.1007/s11192-012-0730-9

Dori, Y. J., Avargil, S., Kohen, Z., & Saar, L. (2018). Context-based learning and metacognitive prompts for enhancing scientific text comprehension. *International Journal of Science Education*, *40*(10), 1198–1220. https://doi.org/10.1080/09500693.2018.1470351

Dunlosky, J., & Rawson, K. A. (2015). Practice tests, spaced practice, and successive relearning: Tips for classroom use and for guiding students' learning. *Scholarship of Teaching and Learning in Psychology*, *1*(1), 72–78. https://doi.org/10.1037/stl0000024

Efklides, A. (2008). Metacognition: Defining Its Facets and Levels of Functioning in Relation to Self-Regulation and Co-regulation. *European Psychologist*, *13*(4), 277–287. https://doi.org/10.1027/1016-9040.13.4.277

Efklides, A., & Misailidi, P. (2010). Trends and prospects in metacognition research. In *Trends and Prospects in Metacognition Res.* (p. 479). Springer US; Scopus. https://doi.org/10.1007/978-1-4419-6546-2

Efstratia, D. (2014). Experiential Education through Project Based Learning. *Procedia - Social and Behavioral Sciences*, *152*, 1256–1260. https://doi.org/10.1016/j.sbspro.2014.09.362

Eggen, P. D., & Kauchak, D. P. (2012). *Strategies and models for teachers: Teaching content and thinking skills* (6th ed). Pearson.

Egorov, E. E., Prokhorova, M. P., Lebedeva, T. E., Mineeva, O. A., & Tsvetkova, S. Y. (2021). Moodle LMS: Positive and Negative Aspects of Using Distance Education in Higher Education Institutions. *Propósitos y Representaciones*, *9*(SPE2), e1104. https://doi.org/10.20511/pyr2021.v9nSPE2.1104

Fini, E. H., Awadallah, F., Parast, M. M., & Abu-Lebdeh, T. (2018). The impact of project-based learning on improving student learning outcomes of sustainability concepts in transportation engineering courses. *European Journal of Engineering Education*, *43*(3), 473–488. https://doi.org/10.1080/03043797.2017.1393045

Fischer, F., Kollar, I., Ufer, S., Sodian, B., Hussmann, H., Pekrun, R., Neuhaus, B., Dorner, B., Pankofer, S., Fischer, M., Strijbos, J.-W., Heene, M., & Eberle, J. (2014). Scientific Reasoning and Argumentation: Advancing an Interdisciplinary Research Agenda in Education. *Frontline Learning Research*, *2*(3), 28–45. https://doi.org/10.14786/flr.v2i2.96

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

Fleur, D. S. (2021). Metacognition: Ideas and insights from neuro- and educational sciences. *Npj Science of Learning*, 11.

Georghiades, P. (2004). From the general to the situated: Three decades of metacognition. *International Journal of Science Education*, *26*(3), 365–383. Scopus. https://doi.org/10.1080/0950069032000119401

Goh, W. W., Hong, J. L., & Gunawan, W. (2014). Exploring Lecturers' Perceptions of Learning Management System: An Empirical Study Based on TAM. *International Journal of Engineering Pedagogy (IJEP)*, *4*(3), 48. https://doi.org/10.3991/ijep.v4i3.3497

Grossman, P., Dean, C. G. P., Kavanagh, S. S., & Herrmann, Z. (2019). Preparing teachers for project-based teaching. *Phi Delta Kappan*, *100*(7), 43–48. https://doi.org/10.1177/0031721719841338

Guo, P., Saab, N., Post, L. S., & Admiraal, W. (2020). A review of project-based learning in higher education: Student outcomes and measures. *International Journal of Educational Research*, *102*, 101586. https://doi.org/10.1016/j.ijer.2020.101586

Hasni, A., Bousadra, F., Belletête, V., Benabdallah, A., Nicole, M.-C., & Dumais, N. (2016). Trends in research on project-based science and technology teaching and learning at K–12 levels: A systematic review. *Studies in Science Education*, *52*(2), 199–231. https://doi.org/10.1080/03057267.2016.1226573

Haug, B. S., & Mork, S. M. (2021). Taking 21st century skills from vision to classroom: What teachers highlight as supportive professional development in the light of new demands from educational reforms. *Teaching and Teacher Education*, *100*, 103286. https://doi.org/10.1016/j.tate.2021.103286

Hernández-Ramos, J., Pernaa, J., Cáceres-Jensen, L., & Rodríguez-Becerra, J. (2021). The Effects of Using Socio-Scientific Issues and Technology in Problem-Based Learning: A Systematic Review. *Education Sciences*, *11*(10), 640. https://doi.org/10.3390/educsci11100640

Hoy, A. W. (2013). *Educational psychology* (12th ed). Pearson.

Jerome, C., Lee, J. A.-C., & Ting, S.-H. (2017). What Students Really Need: Instructional Strategies that Enhance Higher Order Thinking Skills (HOTS) among UNIMAS Undergraduate. *International Journal of Business and Society*, *18*(4), 661–668.

Kaberman, Z., & Dori, Y. J. (2009). Metacognition in chemical education: Question posing in the case-based computerized learning environment. *Instructional Science*, *37*(5), 403–436. Scopus. https://doi.org/10.1007/s11251-008-9054-9

Kluwe, R. H. (1982). Cognitive Knowledge and Executive Control: Metacognition. In D. R. Griffin (Ed.), *Animal Mind – Human Mind* (pp. 201–224). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-68469-2_12

Kober, N. (2015). *Reaching Students: What Research Says About Effective Instruction in Undergraduate Science and Engineering* (p. 18687). National Academies Press. https://doi.org/10.17226/18687

Kokotsaki, D., Menzies, V., & Wiggins, A. (2016). Project-based learning: A review of the literature. *Improving Schools*, *19*(3), 267–277. https://doi.org/10.1177/1365480216659733

Kortam, N., Basheer, A., Hofstein, A., & Hugerat, M. (2018). How Project-Based Learning promotes 7th grade students' motivation and attitudes towards studying biology. *Action Research and Innovation in Science Education*, *1*(2), 9–17. https://doi.org/10.51724/arise.10

Krathwohl, D. R. (2002). A Revision of Bloom's Taxonomy: An Overview. *Theory Into Practice*, *41*(4), 212–218. https://doi.org/10.1207/s15430421tip4104_2

Kroll, D. L. (1988). *Cooperative mathematical problem-solving and metacognition: A case study of three pairs of women* [Doctoral Dissertation]. Indiana University.

Kulakli, A., & Osmanaj, V. (2020). Global Research on Big Data in Relation with Artificial Intelligence (A Bibliometric Study: 2008-2019). *International Journal of Online and Biomedical Engineering (IJOE)*, *16*(02), 31. https://doi.org/10.3991/ijoe.v16i02.12617

Labroo, A. A., & Pocheptsova, A. (2016). Metacognition and consumer judgment: Fluency is pleasant but disfluency ignites interest. *Current Opinion in Psychology*, *10*, 154–159. https://doi.org/10.1016/j.copsyc.2016.01.008

Lai, E. R. (2011). *Critical thinking: A literature review* (pp. 1–50). https://images.pearsonassessments.com/images/tmrs/CriticalThinkingReviewFINAL.pdf

Lavi, R., Tal, M., & Dori, Y. J. (2021). Perceptions of STEM alumni and students on developing 21st century skills through methods of teaching and learning. *Studies in Educational Evaluation*, *70*, 101002. https://doi.org/10.1016/j.stueduc.2021.101002

Li, Q. (2021). Analysis and practice on the training of key ability of students majoring in electronic information in higher vocational education. *Procedia Computer Science*, *183*, 791–793. https://doi.org/10.1016/j.procs.2021.02.130

Liu, C., Bano, M., Zowghi, D., & Kearney, M. (2021). Analysing user reviews of inquiry-based learning apps in science education. *Computers & Education*, *164*, 104119. https://doi.org/10.1016/j.compedu.2020.104119

Loughran, J. J. (2002). *Developing Reflective Practice* (0 ed.). Routledge. https://doi.org/10.4324/9780203453995

Lynch, M. (2020). E-Learning During A Global Pandemic. *Asian Journal of Distance Education*, *15*(1), 189–195.

Masino, S., & Niño-Zarazúa, M. (2016). What works to improve the quality of student learning in developing countries? *International Journal of Educational Development*, *48*, 53–65. https://doi.org/10.1016/j.ijedudev.2015.11.012

McCormick, C. B. (2003). Metacognition and Learning. In I. B. Weiner (Ed.), *Handbook of Psychology* (p. wei0705). John Wiley & Sons, Inc. https://doi.org/10.1002/0471264385.wei0705

McDowell, L. D. (2019). The roles of motivation and metacognition in producing self-regulated learners of college physical science: A review of empirical studies. *International Journal of Science Education*, *41*(17), 2524–2541. https://doi.org/10.1080/09500693.2019.1689584

Miller, E. C., & Krajcik, J. S. (2019). Promoting deep learning through project-based learning: A design problem. *Disciplinary and Interdisciplinary Science Education Research*, *1*(1), 7. https://doi.org/10.1186/s43031-019-0009-6

Morrison, J. A. (2013). Exploring Exemplary Elementary Teachers' Conceptions and Implementation of Inquiry Science. *Journal of Science Teacher Education*, *24*(3), 573–588. https://doi.org/10.1007/s10972-012-9302-3

Muhali, M., Prahani, B. K., Mubarok, H., Kurnia, N., & Asy'ari, M. (2021). The Impact of Guided-Discovery-Learning Model on Students' Conceptual Understanding and Critical Thinking Skills. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, *5*(3), 227–240. https://doi.org/10.36312/esaintika.v5i3.581

Muhali, M., Yuanita, L., & Ibrahim, M. (2019). The Validity and Effectiveness of the Reflective-Metacognitive Learning Model to Improve Students' Metacognition Ability in Indonesia. *Malaysian Journal of Learning and Instruction*, *16*(2), 33–74. https://doi.org/10.32890/mjli2019.16.2.2

National Research Council (Ed.). (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. The National Academies Press.

Negretti, R. (2021). Searching for Metacognitive Generalities: Areas of Convergence in Learning to Write for Publication Across Doctoral Students in Science and Engineering. *Written Communication*, *38*(2), 167–207. https://doi.org/10.1177/0741088320984796

Noguera, I., Guerrero-Roldán, A.-E., & Masó, R. (2018). Collaborative agile learning in online environments: Strategies for improving team regulation and project management. *Computers & Education*, *116*, 110–129. https://doi.org/10.1016/j.compedu.2017.09.008

Ouyang, Y., Yang, G., Zhu, Y., Tan, Q., & Liu, X. (2020). Better regulatory performance without greater cognitive resource expenditure: The effect of motivational states on self-regulation. *Personality and Individual Differences*, *166*, 110170. https://doi.org/10.1016/j.paid.2020.110170

Ozdemir, A. S., Yildiz, F., & Yildiz, S. G. (2015). The effect of project based learning in "ratio, proportion and percentage" unit on mathematics success and attitude. *European Journal of Science and Mathematics Education*, *3*(1), 1–13. https://doi.org/10.30935/scimath/9417

Panadero, E., & Järvelä, S. (2015). Socially Shared Regulation of Learning: A Review. *European Psychologist*, *20*(3), 190–203. https://doi.org/10.1027/1016-9040/a000226

Papaleontiou-Louca, E. (2008). *Metacognition and theory of mind*. Cambridge Scholars Pub.

Peña-Ayala, A., & Cárdenas, L. (2015). A Conceptual Model of the Metacognitive Activity. In A. Peña-Ayala (Ed.), *Metacognition: Fundaments, Applications, and Trends* (Vol. 76, pp. 39–72). Springer International Publishing. https://doi.org/10.1007/978-3-319-11062-2_3

Perry, J., Lundie, D., & Golder, G. (2019). Metacognition in schools: What does the literature suggest about the effectiveness of teaching metacognition in schools? *Educational Review*, *71*(4), 483–500. https://doi.org/10.1080/00131911.2018.1441127

Peters, E., & Kitsantas, A. (2010). The Effect of Nature of Science Metacognitive Prompts on Science Students' Content and Nature of Science Knowledge, Metacognition, and Self-Regulatory Efficacy: Science Metacognitive Prompts. *School Science and Mathematics*, *110*(8), 382–396. https://doi.org/10.1111/j.1949-8594.2010.00050.x

Pintrich, P. R. (2000). The Role of Goal Orientation in Self-Regulated Learning. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of Self-Regulation* (pp. 451–502). Elsevier. https://doi.org/10.1016/B978-012109890-2/50043-3

Porter, A. N., & Peters-Burton, E. E. (2021). Investigating teacher development of self-regulated learning skills in secondary science students. *Teaching and Teacher Education*, *105*, 103403. https://doi.org/10.1016/j.tate.2021.103403

Prayoonsri, B., Tatsirin, S., Suntorapot, D., & Jariya, C. (2015). Factors affecting higher order thinking skills of students: A meta-analytic structural equation modeling study. *Educational Research and Reviews*, *10*(19), 2639–2652. https://doi.org/10.5897/ERR2015.2371

Ralph, R. A. (2016). Post secondary project-based learning in science, technology, engineering and mathematics. *Journal of Technology and Science Education*, *6*(1), 26–35. https://doi.org/10.3926/jotse.155

Rambocas, M., & Sastry, M. K. S. (2017). Teaching Business Management to Engineers: The Impact of Interactive Lectures. *IEEE Transactions on Education*, *60*(3), 212–220. https://doi.org/10.1109/TE.2016.2637327

Reis, A. C. B., Barbalho, S. C. M., & Zanette, A. C. D. (2017). A bibliometric and classification study of Project-based Learning in Engineering Education. *Production*, *27*(spe). https://doi.org/10.1590/0103-6513.225816

Sasson, I., Yehuda, I., & Malkinson, N. (2018). Fostering the skills of critical thinking and question-posing in a project-based learning environment. *Thinking Skills and Creativity*, *29*, 203–212. https://doi.org/10.1016/j.tsc.2018.08.001

Schoenfeld, A. H. (1983). Beyond the Purely Cognitive: Belief Systems, Social Cognitions, and Metacognitions As Driving Forces in Intellectual Performance*. *Cognitive Science*, *7*(4), 329–363. https://doi.org/10.1207/s15516709cog0704_3

Schoenfeld, A. H. (2016). Learning to Think Mathematically: Problem Solving, Metacognition, and Sense Making in Mathematics (Reprint). *Journal of Education*, *196*(2), 1–38. https://doi.org/10.1177/002205741619600202

Schraw, G., Crippen, K. J., & Hartley, K. (2006). Promoting Self-Regulation in Science Education: Metacognition as Part of a Broader Perspective on Learning. *Research in Science Education*, *36*(1–2), 111–139. https://doi.org/10.1007/s11165-005-3917-8

Schraw, G., & Dennison, R. S. (1994). Assessing Metacognitive Awareness. *Contemporary Educational Psychology*, *19*(4), 460–475. https://doi.org/10.1006/ceps.1994.1033

Schraw, G., Olafson, L., Weibel, M., & Sewing, D. (2012). Metacognitive Knowledge and Field-based Science Learning in an Outdoor Environmental Education Program. In A. Zohar & Y. J. Dori (Eds.), *Metacognition in Science Education* (Vol.

40, pp. 57–77). Springer Netherlands. https://doi.org/10.1007/978-94-007-2132-6_4

Schunk, D. H. (2012). *Learning theories: An educational perspective* (6th ed). Pearson.

Sole, F. B., & Anggraeni, D. M. (2018). Inovasi Pembelajaran Elektronik dan Tantangan Guru Abad 21. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, *2*(1), 10. https://doi.org/10.36312/e-saintika.v2i1.79

Sperling, R. A., Howard, B. C., Staley, R., & DuBois, N. (2004). Metacognition and Self-Regulated Learning Constructs. *Educational Research and Evaluation*, *10*(2), 117–139. https://doi.org/10.1076/edre.10.2.117.27905

Sternberg, R. J. (1982). A componential approach to intellectual development. In R. J. Sternberg (Ed.), *Advances in the psychology of human intelligence* (Vol. 1, pp. 413–463). Lawrence Erlbaum.

Sternberg, R. J., Grigorenko, E. L., & Zhang, L. (2008). Styles of Learning and Thinking Matter in Instruction and Assessment. *Perspectives on Psychological Science*, *3*(6), 486–506. https://doi.org/10.1111/j.1745-6924.2008.00095.x

Suhirman, Prayogi, S., & Asy'ari, M. (2021). Problem-Based Learning with CharacterEmphasis and Naturalist Intelligence: Examining Students Critical Thinking and Curiosity. *International Journal of Instruction*, *14*(2), 217–232.

Taber, K. S. (2015). Affect and meeting the needs of the gifted chemistry learner: Providing intellectual challenge to engage students in enjoyable learning. In *Affective Dimensions in Chemistry Education* (pp. 133–158). Springer Berlin Heidelberg; Scopus. https://doi.org/10.1007/978-3-662-45085-7_7

Tai, J., Ajjawi, R., Boud, D., Dawson, P., & Panadero, E. (2018). Developing evaluative judgement: Enabling students to make decisions about the quality of work. *Higher Education*, *76*(3), 467–481. https://doi.org/10.1007/s10734-017-0220-3

Thomas, G. P. (2012). Metacognition in science education: Past, present and future considerations. In B. Fraser, K. Tobin, & C. J. McRobbie (Eds.), *Second International Handbook of Science Education*. Springer Netherlands. https://doi.org/10.1007/978-1-4020-9041-7

Tosun, C., & Senocak, E. (2013). The Effects of Problem-Based Learning on Metacognitive Awareness and Attitudes toward Chemistry of Prospective Teachers with Different Academic Backgrounds. *Australian Journal of Teacher Education*, *38*(3). https://doi.org/10.14221/ajte.2013v38n3.2

Tsai, Y., Lin, C., Hong, J., & Tai, K. (2018). The effects of metacognition on online learning interest and continuance to learn with MOOCs. *Computers & Education*, *121*, 18–29. https://doi.org/10.1016/j.compedu.2018.02.011

van Eck, N. J., & Waltman, L. (2020). *VOSviewer Manual*. Universiteit Leiden. https://www.vosviewer.com/documentation/Manual_VOSviewer_1.6.15.pdf

Veenman, M. V. J. (2012). Metacognition in Science Education: Defi nitions, Constituents, and Their Intricate Relation with Cognition. In A. Zohar & Y. J. Dori (Eds.), *Metacognition in Science Education* (Vol. 40, pp. 21–36). Springer Netherlands. https://doi.org/10.1007/978-94-007-2132-6_2

Vrieling, E., Stijnen, S., & Bastiaens, T. (2018). Successful learning: Balancing self-regulation with instructional planning. *Teaching in Higher Education*, *23*(6), 685–700. https://doi.org/10.1080/13562517.2017.1414784

Vygotsky, L. S. (1981). *Mind in society: The development of higher psychological processes* (Nachdr.). Harvard Univ. Press.

Yang, L., Sun, T., & Liu, Y. (2017). A Bibliometric Investigation of Flipped Classroom Research during 2000-2015. *International Journal of Emerging Technologies in Learning (IJET)*, *12*(06), 178. https://doi.org/10.3991/ijet.v12i06.7095

Yimer, A., & Ellerton, N. F. (2010). A five-phase model for mathematical problem solving: Identifying synergies in pre-service-teachers' metacognitive and cognitive actions. *ZDM*, *42*(2), 245–261. https://doi.org/10.1007/s11858-009-0223-3

Zimmerman, B. J., & Moylan, A. R. (2009). Self-Regulation: Where Metacognition and Motivation Intersect. In D. J. Hacker, J. Dunlosky, & A. C. Graesser (Eds.), *Handbook of metacognition in education* (pp. 299–315). Routledge.

Zohar, A., & Barzilai, S. (2013). A review of research on metacognition in science education: Current and future directions. *Studies in Science Education*, *49*(2), 121–169. https://doi.org/10.1080/03057267.2013.847261

Zohar, A., & David, A. B. (2008). Explicit teaching of meta-strategic knowledge in authentic classroom situations. *Metacognition and Learning*, *3*(1), 59–82. Scopus. https://doi.org/10.1007/s11409-007-9019-4