



Mapping The Eye Tracking Application To Assess Students' Metacognitive Skills In Chemistry Learning

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Abstract:

Metacognitive skills impact learning in a variety of significant and tangible ways, including problem solving. A method that may be employed to assess problem-solving and metacognitive skills is the eye tracking method. The purpose of this research is to conduct systematic analysis and to map the application of eye tracking in chemistry learning, including its relationship to metacognition and problem-solving skills. Thus, it is anticipated that a greater comprehension of how to use the eye tracking and how it has been applied. This research was conducted using the bibliometric method with the assistance of Publish or Perish (PoP), Zotero, and VOSviewer software. The analysis of the data was conducted qualitatively and quantitatively descriptively. Fifty-five (55) articles were analyzed through the utilization of VOSviewer. The results indicate that there is a scarcity of Scopus-indexed journal articles that detail research on the application of eye tracking for assessing metacognitive skills in chemistry learning (in one study). It is therefore imperative to undertake additional research and disseminate the findings. The primary objective of additional research is to ascertain the efficacy of eye tracking. The findings of the analysis also yielded a comprehensive synopsis of the procedures employed in eye tracking for educational purposes, encompassing both chemistry and non-chemistry domains. Additionally, eye tracking has the capability to systematically and comprehensively delineate, examine, and define the learning process, encompassing the application of metacognitive skills in problem solving and learning.

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Introduction

Higher education institutions both domestically and internationally expect students to be self-directed in their learning nowadays. The process by which learners manage their own learning is intricately linked to their self-regulatory skills (Covington, 2009) and metacognitive skills (Rad, 2012; Saemah & John Arul, 2006).

Metacognitive skills have been found to exert several significant and tangible impacts on the learning process, including problem solving. Therefore, it comes as no surprise that numerous scientific studies, including chemistry, examine the relationship between metacognitive skills and problem solving. The role of metacognitive skills in resolving problems in chemistry that have been instructed in the classroom has been the subject of published research even in the past (Muna et al., 2016; Muna et al., 2017). Chemistry is regarded as a challenging academic discipline on account of the abstract nature of its concepts and their relevance to the everyday lives of students (Sirhan, 2007). The discipline of chemistry encompasses three levels of representation: symbolic, macroscopic, and microscopic (Gilbert & Treagust, 2009); conceptual and algorithmic comprehension (Muna et al., 2017; Nuzulia et al., 2018); and chemistry is acquired and refined through experimental investigations that seek to ascertain the causes, mechanisms, and compositions of natural phenomena, particularly as they pertain to composition, structure and properties, transformations, energetic dynamics and materials (Sanjaya et al., 2017).

Prior research on the relationship between metacognitive skills and problem solving in the context of a lesson has employed a variety of approaches, including presenting students with problem-solving tasks on paper and requesting written responses, administering questionnaires measuring metacognitive skills, and even utilizing the "think aloud" method. However, there is a critical need to investigate and comprehend the application of metacognitive skills in learning, particularly when problem solving is critical, given the significance of metacognition (Horsley et al., 2014). It has been discovered that the validity of the employed methodologies is frequently questioned. As a consequence, researchers specializing in education have endeavored to develop novel explanations for learning through the implementation of diverse research methodologies (Hanuscin, 2007).

Educators have only recently begun to take notice of the eye tracking method, in spite of psychologists' extensive use of it (Horsley et al., 2014; Rayner, 2009). The method is appealing due to its potential to unveil significant facets of the learning processes of students through the provision of insight into how they distribute their visual attention (Horsley et al., 2014). The eyes serve two primary functions in daily activities and learning namely to seek for and identify objects and to guide actions in order to apply the information gathered in the first function (Land & Tatler, 2009). Eye tracking is an exceptionally well-suited technique for examining variations in students' attentiveness throughout the learning process, including problem-solving. Furthermore, it is linked to the application of metacognitive skills during solving problems derived from the chemistry lesson that has been taught.

A systematic analysis of eye movement studies that are associated with learning allows educators to gain a more comprehensive understanding of how to apply eye tracking and how it has been employed. The objective of the conducted research is to determine whether eye tracking can be utilized to assess metacognitive skills in

chemistry learning. This identification is evident through the following visualizations: (1) the network of research topics (themes/keywords); (2) the novelty and profundity of research topics (themes/keywords); and (3) the density of research. Furthermore, an outline (description) of the methodologies employed to utilize eye tracking for educational purposes (encompassing both chemistry and non-chemistry).

Research Method

The method utilized in this research was modified from the bibliometric method described by [Fahimnia et al., \(2015\)](#). The bibliometric method is a technique utilized to assess research by analyzing a variety of compiled literatures ([Ellegaard & Wallin, 2015](#)). The objective of this method was to assess and analyze research findings in order to generate insights into the influence of completed research, collaborative efforts, and emerging trends pertaining to the subject matter which is, in this case, the eye tracking for evaluating students' metacognitive skills in chemistry learning.

Bibliometric method is one of the quantitative research due to its utilization of a statistical approach to assess literature ([Reuters, 2008](#)). The sole statistical approach employed in this research was quantitative descriptive analysis. Subsequently, in an effort to refine the research findings and address the concerns raised in the conducted research, a bibliometric analysis was conducted and qualitatively explained. The researcher's inclination to investigate issues through both quantitative and qualitative means was grounded in the findings of ([Velasco et al., 2012](#)), who assert that bibliometric analysis encompasses both qualitative and quantitative explanations of topics. Then following are the general procedures for bibliometric research.

The Determination of Search Keywords

The literature review was initiated in 2022 and last revised in October 2023. Publish or Perish (PoP) software was utilized to conduct the search, which incorporated the following keywords: eye tracking, use of eye tracking, eye tracking in learning, eye tracking in chemistry learning, metacognitive or metacognition skills, metacognitive or metacognition skills in chemistry learning, eye tracking and metacognitive or metacognition skills, eye tracking and metacognitive or metacognition skills in chemistry learning. The Crossref database was the source of every article analyzed between 2018 and 2023, with a maximum of 500 articles. Crossref was utilized due to the fact that its utilization of DOI links grants it the ability to furnish dependable and enduring hyperlinks. The criteria for selecting articles for analysis was that the article must be in a journal. The articles from proceedings, newspapers, periodicals, and e-books were excluded from bibliometric analysis using VOSviewer; instead, they served as supplementary references when conducting discussions.

Initial Search Results

The Publish or Perish (PoP) software conducted an initial search using keywords selected, including "eye tracking" and "metacognitive skills in chemistry learning." Following this, only journal articles were chosen to advance to the stage of **search result refinement**.

Refinement of The Search Results

The researchers re-selected articles from the initial search results in accordance

with the predetermined criteria. The criteria consist of the following.

1. The articles originate from journals that are indexed by Scopus and may or may not have quartiles. A quartile is a system of evaluating reputable journals according to their respective subject areas. Additionally, the title, author's country of origin, journal name, publisher, year of publication, and quartile of the articles were assessed.

Scopus-indexed journals were utilized as references due to (1) the quality standardization. Scopus journals are renowned for their stringent quality criteria. Therefore, researchers can rely on the information published in these journals. (2) International recognition or global recognition: articles that are published in Scopus journals bestow the authors and research with international recognition. This contributes to the development of one's academic standing and professionalism. (3) Measurement of impact. The utilization of Scopus journals for publication enables researchers to monitor the influence of their own research within the scientific community. Thus, (4) it fosters innovation and cross-disciplinary collaboration.

Scopus journals are a cornerstone of the scientific research community. Scopus facilitates the exchange of knowledge, the demonstration of the significance of research, and collaboration among researchers. The definition and conceptual framework of Scopus journals elucidate the significance attributed to quality standards, worldwide accessibility, and the contribution to the advancement of scientific knowledge. These journals provide the scientific community with an indispensable resource of knowledge.

2. The article's keywords should consist of eye tracking, metacognitive skill or metacognition skill, problem solving, either as a discussion within the article or as distinct themes. Each of these keywords remains relevant to the process of acquiring knowledge and/or learning chemistry.

The researchers reevaluated the keywords due to the fact that articles not specifically related to education might still be permitted in the Initial Search Results.

The selected articles (simultaneously with the selection process) were imported into the Zotero software to facilitate subsequent analysis.

Compiling the Initial Data Statistics

All pertinent details pertaining to the article were exported in RIS format for analysis. This included the title, author's country of origin (with particular emphasis on the first author), abstract, keywords, and journal specifications (including volume, issue, and publication year). The purpose of the analysis is to classify the articles according to the ranking of the journal (Q), author's country of origin, publisher, and year of publication.

Analysis of Data

VOSviewer software was utilized for the bibliometric data analysis in this research, which has the following objectives: (1) to visualize the network of research topics (themes/keywords); (2) to visualize the novelty of research topics (themes/keywords); and (3) to visualize the density of research. Furthermore, an outline (description) of the methodologies employed to utilize eye tracking for

educational purposes (encompassing both chemistry and non-chemistry) is provided, with particular emphasis on ascertaining metacognitive skills and problem solving.

Results and Discussion

Initial Search Results and Refinement of The Search Results

The initial search conducted using the Publish or Perish (PoP) software and the search keywords "eye tracking and metacognitive skills in chemistry learning" yielded a total of 500 articles encompassing a wide range of subject matters. Table 1 presents the distribution of the quantity of articles according to the category of article.

Table 1. Initial Search Results

Article types	Number of articles
Book	3
Book Chapter	81
Book Section	1
Dataset	1
Editted Book	1
Journal	169
Monograph	2
No Type	1
Other	8
Peer Review	28
Posted Content	42
Proceeding	161
Reference Book	1
Reference Entry	1
Total	500

The search results retrieved using PoP indicate the presence of a diverse collection of articles, some of which employ distinct terminology but maintain the same structure, as in the cases of Book Chapter and Book Section; Book and Reference Book.

The initial selection results exclusively include journal articles that were included in the search results. The process of refinement search results yielded 169 articles. The refinement search results based on the predetermined criteria yielded 55 articles. This indicates that 114 articles failed to meet the predetermined criteria. Following this, up to 55 articles were analyzed using VOSviewer. The 114 articles that do not meet the criteria can be detailed as follows: 72 articles are not relevant (keywords and journal indexation), 35 articles that have appropriate keywords but are not from journals indexed by Scopus, and there are 7 articles that are duplicated in the PoP database. Table 2 presents a comparison of the citation matrix data obtained from the search results.

Table 2. Comparison of the Citation Matrix Data from the Search Results

Data	Initial Search Results	Refinement Search	Finishing Refinement Search
Papers	500	169	55
Citations	1510	923	549
Cites/Year	302.00	184.60	109.80
Cites/Paper	3.02	5.46	9.98
Author/Paper	2.37	2.57	2.80
h-index	17	12	10
g-index	30	26	23
hI-norm	10	9	7
hI-annual	2.00	1.80	1.40
hA-index	10	8	6

Statistics of the Initial Data

Following the refinement of the article search criteria, 55 articles are selected, stored in Zotero, and data collection was initiated. The collected information comprised the following: title, author's country of origin, journal name, publisher, year of publication, and quartile. The journal classification (Scopus quartile) is presented in Table 4, while the distribution of the author's country of origin (first author) is illustrated in Table 3.

Table 3. Author's Country of Origin

Country of Origin	Number
United States of America	12
Saudi Arabia	2
Belgium	2
China	4
Georgia	1
German	4
India	1
Indonesia	13
Latvia	1
London	1
Morocco	1
Netherlands	2
Norway	1
Pakistan	1
New Zealand	1
Spanish	1
Taiwan	2
Thailand	3
Turkey	2
Total	55

The findings presented in Table 3 indicate that researchers hailing from the Indonesia and USA frequently undertake research pertaining to the subject matter of "eye tracking, metacognitive skills, problem solving" as it relates to the learning and/or chemistry learning.

Table 4. Journal Ranking (Quartile Scopus)

Quartile copus	Number
Q1	29
Q2	10
Q3	6
Q4	2
Non Quartile	8
Total	55

The international community discusses the findings of research pertaining to the subject matter of "eye tracking, metacognitive skills, problem solving" in the context of learning and/or learning chemistry, as indicated by the data in Table 4. The findings of these research are also eligible for publication in journals indexed by Scopus, ranging from non-quartile to Q1. The following are examples of titles of articles that were published successfully in Scopus Journals from Q1 to Q4:

1. Non quartile: Eye-tracking and metacognitive skills: A review on the use of eye tracking for measuring students' metacognitive skills in chemistry learning (Muna & Bahit, 2020); The student metacognitive skills and achievement in chemistry learning: correlation study (Arami & Wiyarsi, 2020).
2. Q1: Eye-tracking and artificial intelligence to enhance motivation and learning (Sharma et al., 2020); Towards collaborative and intelligent learning environments based on eye tracking data and learning analytics: a survey (Wang et al., 2021).
3. Q2 :Fixation duration and the learning process: an eye tracking study with subtitled videos (Negi & Mitra, 2020); It is all in the surv-eye: can eye tracking data shed light on the internal consistency in self-report questionnaires on cognitive processing strategies?(Chauliac et al., 2020).
4. Q3: Identifying learning style through eye tracking technology in adaptive learning systems (Guabassi et al., 2019); Metacognitive skill profiles of chemistry education students in solving problem at low ability level (Ijirana & Supriadi, 2018).
5. Q4 :Ninth-grade students' metacognitive experience from learning with the metacognitive experience learning box in the equilibrium of moments (Sanium & Buaraphan, 2021); Improving classroom learning environment for enhancing reading comprehension through metacognitive strategies (Ayaz et al., 2023).

Table 5 illustrates a selection of publishers that frequently release articles pertaining to "eye tracking, metacognitive skills, problem solving," with a particular emphasis on the domains of learning and chemistry learning. These results indicate that publications on eye tracking, metacognitive skills, and problem solving are dominated by multidisciplinary publishers and conference proceedings. This pattern indicates that eye tracking research in the context of learning, particularly chemistry learning, is still developing at an exploratory stage with an emphasis on methodological aspects. The relatively limited number of publications in reputable education and chemistry education journals suggests that the eye tracking approach has not yet been fully adopted as a primary analytical framework in metacognition studies. Furthermore, the fragmented distribution of publications across various publishers with low contributions reflects a lack of methodological consolidation and theoretical integration. These findings emphasize the need for systematic observation

based on an established metacognitive framework to strengthen the direction and depth of future research.

Table 5. Publisher

Publisher	Number
American Society for Cell Biology	1
Association for Research in Vision and Ophthalmology Inc.	1
Common Ground Research Networks	1
Ekip Buro Makineleri A.S.	1
Elsevier BV	5
Elsavier Ltd.	3
Emerald Group Publishing Ltd.	1
Eurasian Society of Educational Research	1
European Association for Research on Learning and Instruction	1
Frontiers Media S.A.	2
Gate Association for Teaching and Education	1
Hampstead Psychological Associates	2
Inderscience Enterprises Ltd.	2
Institute of Advanced Engineering and Science (IAES)	1
Institute of Electrical and Electronics Engineers Inc.	1
International Group for Eye Movement Research	2
IOP Publishing Journal of Physics: Conference Series	6
MDPI AG	1
Oxford University Press	1
Routledge	1
SAGE Publications Inc.	2
SAGE Publications Ltd	1
Springer Nature	1
Springer New York	3
SpringerOpen	1
Supporting Academic Initiatives Foundation	1
Taylor and Francis Ltd.	2
Universitas Negeri Makassar- Faculty of Languages and Literature	1
Universitas Negeri Semarang (UNNES)	1
University of Latvia, Institute of Mathematics and Informatics	1
Wiley-Blackwell	1
Wiley-Blackwell Publishing Ltd	4
World Association for Sustainable Development	1
Total	55

The yearly trends in the publication of research results pertaining to articles that explore the intersection of "eye tracking, metacognitive skills, or metacognitive skills, problem solving" in the context of learning and also chemistry learning are illustrated in Figure 1.

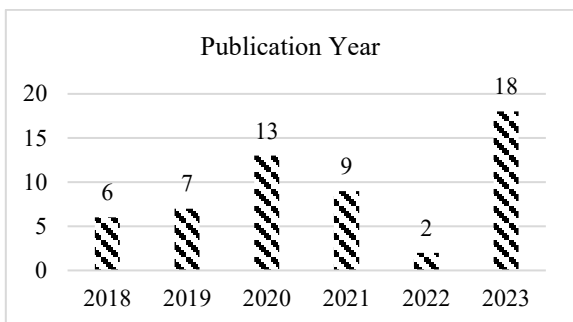


Figure 1. Publication Year

Articles that address the topic of "eye tracking, metacognitive skills, problem solving" in the context of learning and/or chemistry learning either in one discussion or separately are subjected to additional VOSviewer analysis.

The VOSviewer utilized was an offline (stand-alone) version. Three distinct categories of visualizations are supported by this offline VOSviewer: density, network, and overlay (Wibowo, 2021). A network visualization depicts the interconnections among various elements such as authors, topics, articles, affiliations, and countries. Additionally, overlay resembles a network visualization, with the addition of an average year that facilitates the understanding of the evolution or development of a research topic. Density can indicate the degree of saturation pertaining to a given subject matter. Subjects that are featured in the article's keywords and are progressively being discussed will be presented in a more somber hue.

The analysis in this research was conducted according to the titles and abstracts, so a mapping was achieved concerning the application of eye tracking to assess metacognitive skills in the context of chemistry education. Mapping was conducted by utilizing the outcomes of the following identifications: (1) visualization of the research topic network (comprising themes and keywords); (2) visualization of the novelty of the research topic (comprising themes and keywords); and (3) visualization of the density of research.

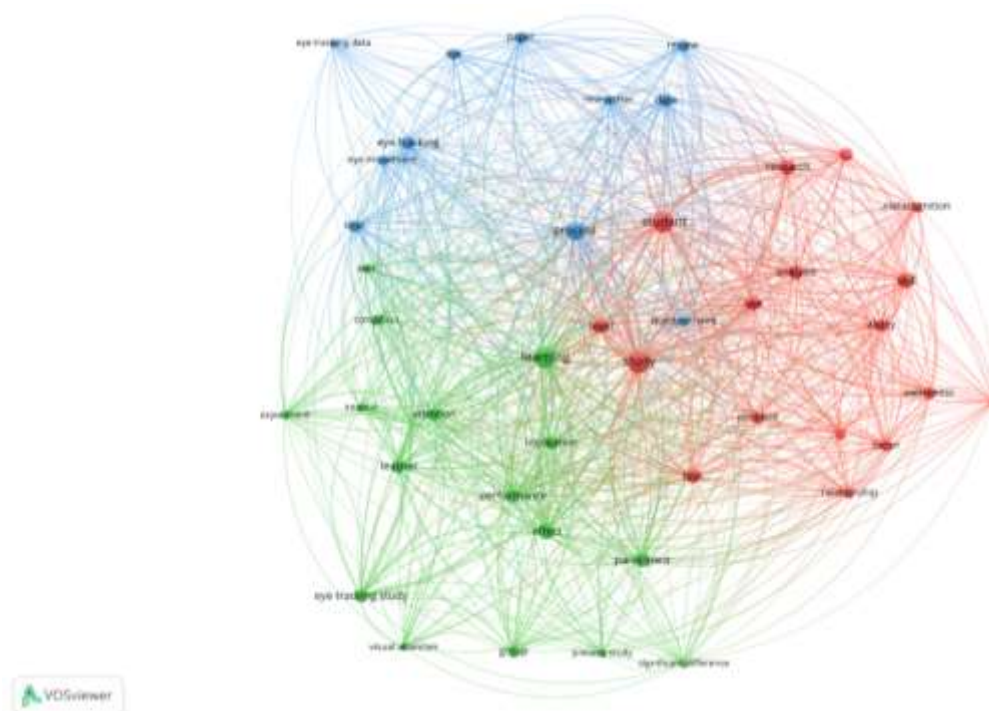


Figure 2. Visualization of The Research Topic Network (Themes and Keywords)

Based on the bibliometric form shown in Figure 2, there are three main clusters (red, green, and blue) that represent the interconnectedness of research themes in the field of eye tracking and metacognition in learning. These three clusters do not stand alone, but are interconnected and demonstrate the conceptual integration of cognitive processes, metacognition, and visual mechanisms in the context of learning.

The red cluster is dominated by the keywords study, student, awareness, skill, problem, metacognition, and task. This indicates that the primary focus of research in this cluster is on the role of student metacognition in completing learning tasks and solving problems. The findings of this study align with the metacognition theory proposed by (Flavell, 1979) which states that individual awareness of the metacognitive awareness process is an important factor in learning success. In addition (Schraw & Dennison, 1994) emphasized that metacognitive skills, such as planning, monitoring, and evaluating, contribute significantly to students' academic performance.

The green cluster displays the most frequently occurring keywords: learning, learner, performance, eye tracking study, visual attention, and interest. This cluster represents research that focuses on the relationship between visual attention and learning performance. The use of eye tracking allows researchers to directly observe how students focus their visual attention during the learning process. According to (Rayner, 1998) Eye movement patterns reflect ongoing cognitive processes, making eye tracking a valid method for assessing attention and visual information processing. The association of the green cluster with the keyword metacognition suggests that visual attention is not only related to basic cognitive aspects but also to metacognitive regulation in learning.

Meanwhile, the blue cluster, consisting of the keywords "process," "eye tracking," "eye movement," "eye," and "review," indicates the research's focus on the methodological and processual aspects of eye tracking studies. This cluster directly links the learning process to eye movement measurements as indicators of cognitive and metacognitive activity. The relationship between the blue and red clusters indicates that metacognition cannot be separated from the learning process itself but is integrated into students' visual and cognitive activities. This aligns with the findings of (Holmqvist et al., 2011) which states that eye movement data can be used to identify a person's learning strategies and level of metacognitive awareness while completing a task.

Overall, the interconnections between the clusters indicate that eye tracking research has a strong correlation with studies on metacognition in learning. The green cluster represents the role of eye tracking as a tool for uncovering visual attention and learning interest, while the blue cluster emphasizes its connection to the learning process in general. The red cluster reinforces the position of metacognition as central to effective learning activities. Thus, these results support the view that integrating eye tracking into educational research can provide a deeper understanding of how metacognitive processes occur and how they influence learning performance.

Visualization of the Novelty of the Research or Time Analysis

This research also mapped the novelty of research in the field of study on "eye tracking, metacognitive skills or metacognitive skills" in the context of learning and/or

learning chemistry, after considering the frequency of frequently appearing keywords. The visualization of research novelty or time analysis is depicted in Figure 3.

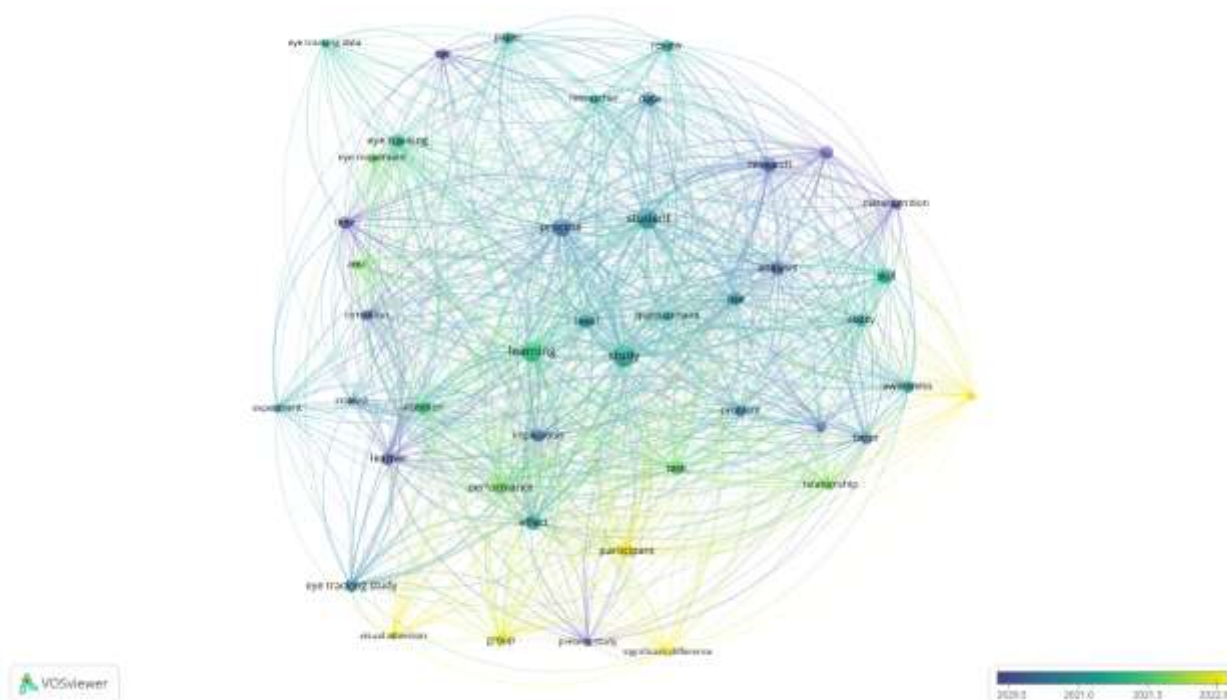


Figure 3. Visualization of the Novelty of the Research or Time Analysis

Figure 3 shows a keyword co-occurrence network generated with VOSviewer. Bright clusters are a new research theme that has not been widely studied. The co-occurrence network results group keywords related to learning or learner performance, metacognitive or metacognitive strategy or metacognitive skills, visual attention, and eye tracking studies. From the co-occurrence network results, it can be concluded that integrating eye tracking as a measure of visual attention with metacognitive learning is starting to be feasible. This is possible because eye tracking is often used to capture visual attention and information processing in learning materials based on text, diagrams, and multimodal representations (Jarodzka et al., 2017), so that it can be a new research topic that can be carried out to understand how students monitor and adjust their learning strategies.

The dark color cluster contains keywords such as eye tracking study, learner, and implication, indicating that the topic has been frequently used, such as eye tracking to understand learning behavior or information processing. These results also found that eye tracking research in educational research is more often focused on multimedia learning, reading, and problem-solving, while more specific integrations of eye tracking directly into specific metacognitive constructs tend to be more recent and less widespread (Liu & Cui, 2025).

Visualization of The Density of Research

Figure 4 illustrates the saturation or density of research pertaining to "eye tracking and metacognitive skills" as it relates to the process of learning and/or learning chemistry.

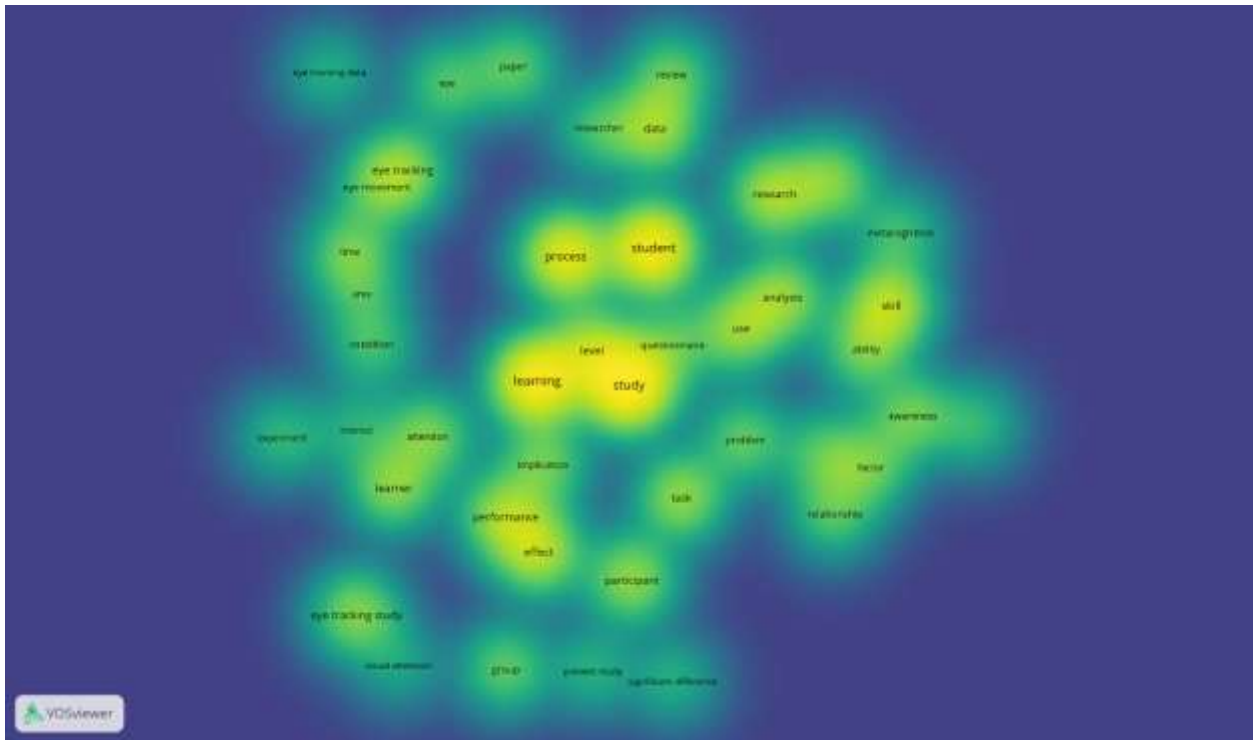


Figure 4. Analysis of The Density of Research

Bright colors indicate that much research has been conducted on eye tracking, metacognitive skill, performance, study, as depicted in Figure 4. However, research has been undertaken chiefly as the individual topic, such as just about eye tracking in learning or just about students' metacognitive skills in learning. Can see at the dark color. The dark colors signify that little research has been conducted on the aforementioned topics or keywords. We can say that still little research that conduct between 2 topics in one theme research such as eye tracking for measuring metacognitive skill in learning or chemistry learning.

Based on the visualization results and analysis of the articles obtained, we can agree that the keywords eye tracking, metacognitive skills, problem-solving in chemistry learning and/or learning are still very interesting to research with various problems that can be the focus of research. This is also because eye tracking is an established method for observation and data collection in behavioral aspects, e.g., movement of the eyes or pupil dilation (Tobii, 2023). By providing objective and accurate data, it helps researchers gain an insight into the learning process. In addition, there is the possibility of measuring the cognitive effort required for a task with pupillometric data.

Considering that metacognitive skills have been shown to influence students' conceptual understanding, these skills are associated with motivation and learning achievement (Syahmani, S. et al., 2023) and may also be a factor in problem-solving abilities. Therefore, further research needs to be carried out and publication of research results needs to be attempted in Scopus indexed journals, so that the results obtained are more useful. This further research could focus on how effective eye tracking is in measuring students' metacognitive skills in an experimental research setting. As well as considering factors that influence the accuracy of measurement results.

The three visualizations presented show the scarcity of studies examining eye tracking and metacognitive skills in the same investigation, particularly in chemistry learning. Nevertheless, the description of the methodologies of eye tracking application in the variety of learning subjects can be drawn. A summary of the various types of eye trackers and supporting devices applicable to research in the field of education (learning) can be derived from the selected articles and other corroborating references: (1) head-stabilized eye tracking (eye tracking positioned on the head) (Gotardi et al., 2020); (2) remote eye tracking (eye tracking device positioned beneath the computer screen); and (3) mobile eye tracking (a pair of tracking glasses connected to the tablet); (4) computer, (5) other research data collection instruments. Multiple factors must be taken into account when deciding which type of eye tracker to utilize (Havanki & VandenPlas, 2014a). These include the following: (1) eye tracking versus gaze tracking, (2) configuration of hardware, (3) monocular versus binocular tracking dan (4) dark pupil versus bright pupil.

The procedures employed in the educational application of eye trackers depends on the variables under investigation or measurement by the eye tracker and the analysis of the obtained data. The followings detail number of procedures pertaining to the use of eye trackers and data analysis.

1. The use of multimedia based learning to assess student cognitive abilities through eye tracking is done by assigning tasks in text and images compared with sound or video (Antonietti et al., 2015). Then, immediately following completion of the task, all participants completed a questionnaire on metacognitive skills. At that time, an eye tracking device is placed within the monitor screen at a distance of approximately 60 - 70 cm from the computer screen to the student in order to measure eye movement variability and metacognitive skills. The eye tracking data results were analyzed based on a spatial scale (measured based on space) consisting of a fixed count at each AOI and the fixation rate (count/s) of the area of interest (AOI). Measuring metacognitive skills using eye-tracking through multimedia-based learning produces two main things, namely (i) a learning method that uses audio+images instead of text+images and (ii) the results of observing eye-tracking data using a metacognition questionnaire in learning form of correlation of visual attention with metacognitive skills. An increasing number of corrections on the audio+visual task were observed in response to these correlation results.
2. Analyzing student problem solving skills through examination of visual attention while performing chemistry problems identified the periodic table of elements. Eye tracking and retrospectively thinkaloud techniques have been used to assess the rationale for students' performances, i.e. to analyse strategies and problems they had faced when solving tasks (Tóthová et al., 2021). The data from the eye-tracker were submitted to a quantitative analysis-time fixation duration evaluation on predefined areas of interest. Heatmap dan scanpath analysis was also shown in AOI and TFD (as can be seen in Figure 5.). A qualitative analysis of the student procedure was also facilitated by the Thinkaloud method, which supported the eye tracking record and the student transitions.

GazePoint eye camera GP3 with a 60 Hz sampling rate 0.5–1° visual angle accuracy was used to record students' eye movements. A calibration of nine points

was performed prior to each recording. The screen size was 17 in. with 1024 × 800 resolution. There was a free head for the participants. The researcher used a second monitor to check the tracking. To analyse this information, a version 5.0 of the OGAMA Open Gaze and Mouse Analyzer has been used. According to the average fixation durations (200–300ms) (Holmqvist et al., 2011), which can vary from 50–75 ms to 500–600 ms (Hyrskykari et al., 2008), the fixation was recorded when a subject's gaze stabilized for at least 300 ms.

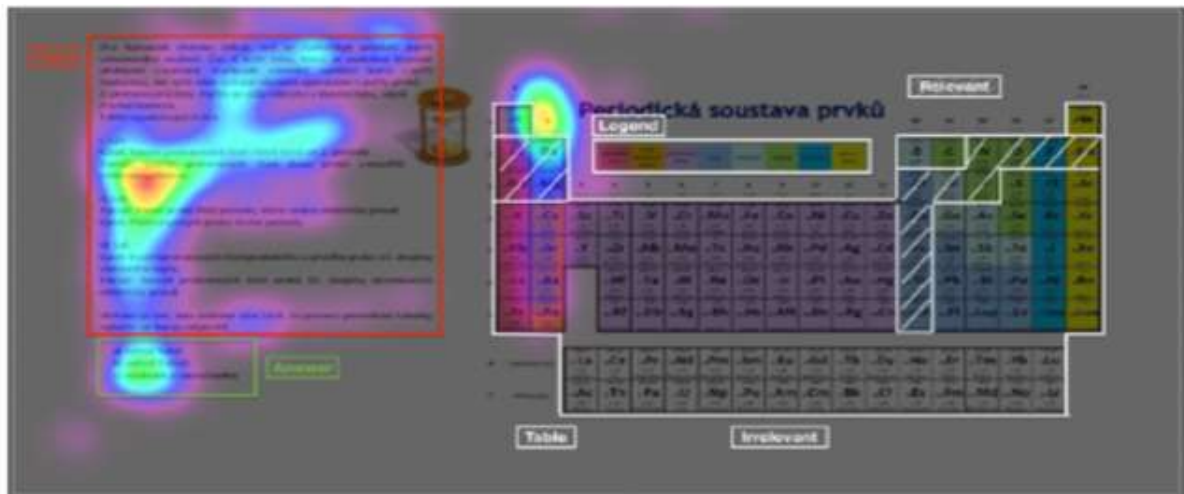


Figure 5.a

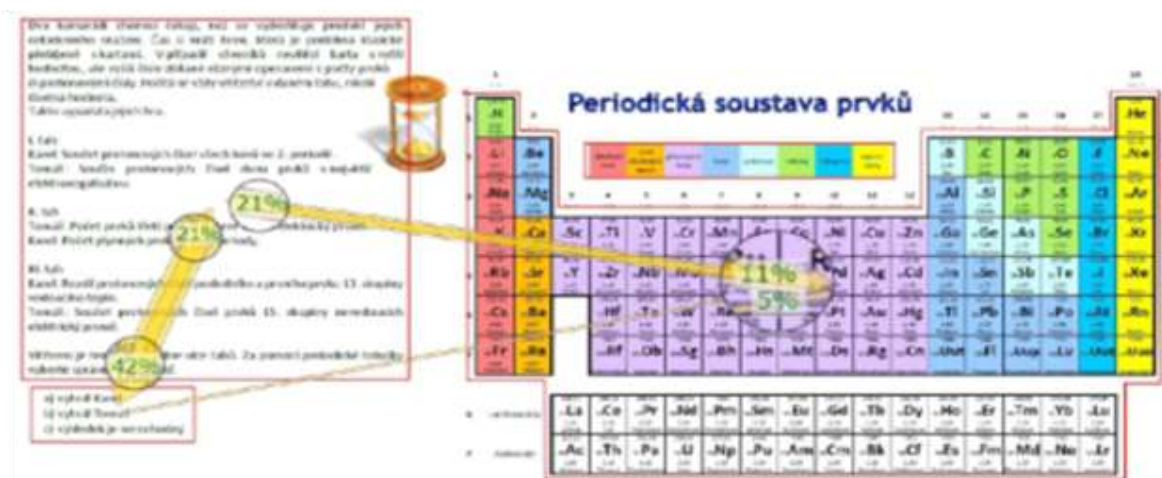


Figure 5.b

Figure 5. (Top) Heatmap of Students who guessed the answer and did not use the periodic table. (Bottom) Scanpath of Students' eye-movement transitions among task's AoIs (Tóthová et al., 2021). In general, we can state that eye tracking data analysis includes 3 methods (Havanki & VandenPlas, 2014b), namely Area of Interest (AOIs), scanpath analysis, and heatmaps.

Apart from paying attention to the type of eye tracker, supporting devices, procedures for using and analyzing eye tracker results, there are other factors that researchers also need to pay attention to when using eye trackers and analyzing the resulting data, namely: (1) consistent eye movements, (2) identification of the Area of Interest (AOI), which serves as an indicator in the learning process, (3) movement intensity throughout the experimental procedure, (4) distance between the eyes, (5)

lighting; and (6) the calibration process of the eye tracking device before conducting the research (Muna & Bahit, 2020).

The following additional reference sources may serve as a foundation for research concerning eye tracking and problem solving or metacognitive abilities in learning and/or learning chemistry.

1. Eye Tracking Metodology (Duchowski & Duchowski, 2007);
2. Eye Tracking for Chemistry Education Researcher (Jessica et al., 2018)
3. Eye Tracking in Chemistry Education Research: Study Logistic (Hansen & VandenPlas, 2018);
4. Utilizing Eye Tracking Technology to Promote Students' MetaCognitive Awareness of Visual STEM Literacy (Sommer et al., 2016);
5. Student's Perspective and Teachers' Metacogniton: Application of Eye-Tracking in Education (da Silva et al., 2021);
6. Eye-Tracking in Immersive Virtual Reality for Education: A Review of the Current Progress and Applications (Mikhailenko et al., 2022);
7. How Eye Tracking Can Inform Discipline Based Educational Research (Vandenplas, 2019);
8. Eye Tracking for Diverse and Advanced Learning Techniques in Chemistry Education (Administrator, 2020);
9. Metacognitive Skill Profiles of Chemistry Education Students in Solving Problems at Low Ability Level (Ijirana & Supriadi, 2018)
10. What are Students' Learning and Experience in an Online Learning Tool Designed for Cognitive and Metacognitive Skill Development? (Visser & Flynn, 2018);
11. Physics Learning with Metacognitive Approach through Problem Based Learning (PBL) and Reciprocal Learninf (RL) model Viewed from Students' Critical Thinking Skill (Sulasih et al., 2018).

This research is subject to various limitations.

1. The quantity of articles specified by the Publish or Perish (PoP) software during the search process.
2. There still needs to be more depth in the researchers' discussion of the results of the VOSviewer data analysis used.
3. The search is restricted to articles exclusively published in journals indexed by Scopus due to utilizing Scopus journals as criterion.
4. The fact that human resources consisting of only two individuals marginally impedes the qualitative analysis of articles, particularly in regards to the discourse surrounding eye tracking procedures in education (learning).

It is therefore imperative that future research be enhanced.

The researchers are interested in collaborating with other observers of teaching and learning, metacognitive experts, and technology experts, particularly in eye-tracking, to conduct additional research on the use of eye-tracking to measure students' metacognitive skills once the results of the paper analysis are complete. An examination of instruction and learning has been conducted using diverse methodologies, one of which is eye-tracking. Eye-tracking allows educators to gain new insights into the learning process and provide learners with guidance and feedback. Additionally, it enables learning researchers to characterize the student learning process, including the

application of metacognitive skills, in a comprehensive and systematic manner (Horsley et al., 2014).

Chemical substances that researchers are contemplating utilizing as subjects for additional investigations concerning the application of eye-tracking technology to assess students' metacognitive skills in chemistry learning include those pertaining to chemical bonds, chemical equilibrium, solubility, and the product constant (Muna & Bahit, 2020). The researchers have employed these chemical substances in their investigations to assess metacognitive skills pertaining to the solution of chemical problems. Previous research conducted measurements through manual problem-solving of chemical problems and the completion of metacognitive skills questionnaires, rather than employing the eye-tracking method.

An exegesis of potential future research designs derived from the discourse in this article involves the implementation of multimedia-driven chemical education, wherein chemical problems are presented throughout the learning process and evaluated via essay questions at the conclusion of the program. Essay questions are generated using predetermined chemical material in three distinct formats: text, images, and audio (each individually). Eye-tracking is utilized to assess students' metacognitive skills while they solve chemical problems containing three types of questions; the data is analyzed on spatial and temporal dimensions. The students were then interviewed following their responses to the prepared metacognitive skills questionnaire. It is anticipated that the results of this advanced research will provide a comprehensive outline of the types of learning opportunities and challenges that effectively engage students' metacognitive skills, thereby enhancing their problem-solving skills.

Conclusion

The results of this research examining the application of eye tracking to assess metacognitive skills in chemistry learning show that there are 55 articles using keywords "eye tracking, metacognitive skill, including problem solving" in education (learning) and chemistry learning. Furthermore, an analysis of the distribution of researchers from the Indonesia and USA, and the year of publication coincided with the highest number of effectively published studies in Scopus journals is 2020 and 2023. Thus, it can be stated that the number of researchers who publish a single study on eye tracking and metacognitive skills in education and/or learning chemistry in journals indexed by Scopus is relatively small. Subsequent investigations may center on the standardization of eye tracking's efficacy in assessing the metacognitive skills of students, utilizing experimental research environments. Before beginning the experiment, researchers must also concern the variables that affect the precision of the eye tracking tool's measurement results, including illumination, distance from the user, and the eye tracking calibration procedure. Despite the assertion that there is a paucity of research concerning eye tracking and metacognitive skills (should this become a topic of conversation), a description of the methodologies entailed in utilizing eye tracking for education and/or chemistry learning is still attainable.

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