Eye-tracking and metacognitive skills: A review on the use of eye-tracking for measuring students’ metacognitive skills in chemistry learning

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Abstract. This study presents a review of empirical studies on eye-tracking in the education field and aims to describe the use of eye-tracking methods to measure students’ metacognitive skills in chemistry learning. Eighty papers published from the 2000s to 2018 that containing major discussion on students’ metacognitive skills in chemistry learning and the use of eye-tracking were selected for review and analysis. Content analysis for 6 month of the selected papers showed that (1) the eye-tracking for measuring students’ metacognitive skills in chemistry learning was employed by recording all eye movement activities with eye tracker placed under the computer screen with a distance of 60-70 cm from the users (students) and they can freely move the eye for solving the chemistry problems with a predetermined duration of time; (2) analysis of temporal and spatial data of eye-tracking showed a correlation between eye movement and increased metacognitive skills, in which the stabilization of students' views on objects observed between 66-416 ms reflected both eyes and mind worked actively. Thus, researchers can employ the eye-tracking method to comprehensively investigate and describe students’ metacognitive skills in chemistry learning and also can be a metacognitive tool for reflective self-assessment in learning.

1. Introduction

Metacognitive skills have several significant and important influences in learning, one of which is problem-solving. Previous studies related to metacognitive and problem-solving skills from learning used many methods such as giving problem-solving questions that are presented on paper and answered by students, giving questionnaires to metacognitive skills, even engaging the process of thinking aloud [1]. In reality, the need to examine and understand the use of metacognitive skills in learning especially for the problem-solving processes is important since the students’ metacognitive skills are very important for their learning [2]. For this reason, researchers in the field of education finally looked for various research methods that were developed differently in the hope of presenting an explanation of the learning process from various perspectives [3].

The eye-tracking method that has been used intensively by psychologists [4], [5], has just begun to draw attention to educators in recent years. This method is interesting because it can reveal important
aspects of student learning by providing insight into the allocation of students' visual attention [2]. It is known that in daily tasks and learning, the eye has a role (1) to find and recognize objects and then, (2) direct actions to utilize the information that has been obtained from the former role [6]. The use of the eye-tracking method is certainly very suitable to learn the differences in the process of students' attention when performing problem-solving and associated with the use of metacognitive skills during problem-solving from the chemistry learning that has been taught. Therefore, in the current study, by conducting a broad literature review, we have made efforts to explore how eye-tracking is used in learning specifically for measuring students' metacognitive skills, how to analyze data obtained from the results of eye-tracking up to trace the advantages and disadvantages of measurement of metacognitive skills in chemistry learning.

2. Literature review
There are 4 points of the literature as the basis for understanding this study, as follows:

- The importance of metacognitive skills in chemistry learning and its relationship with 21st-century skills. Metacognitive skills are part of 21st-century skills that are classified into skills group with ways of thinking along with other skills namely creativity, innovation, critical thinking, problem-solving and decision making[7]. Various studies have shown the relationship and influence of metacognitive skills on one's skills, both in mastering the concepts of material, learning outcomes, and problem-solving [8], [9], [10], [11], [12]. Metacognitive is generally considered as the key to deeper, more durable and easier in transferring learning. It is important for chemistry instructors and students to understand there are at least two reasons why metacognitive skills are important, namely as a form of awareness of one's thoughts and their usefulness in developing understanding, and awareness and thinking control that has a significant influence on problem-solving skills [13].

- The use of eye-tracking. Eye-tracking is a method used to determine the pattern of eyeball movements and the direction of the eye, by analyzing visual attention [14]. In the field of education, eye tracking is used to analyze reading skills, information processing[1], multimedia learning [15], and science problem-solving strategies [16]. Analysis of eye-tracking data which is often used to measure fixation is the proportion of time spent on each area of interest (AOI), average fixation duration, fixation count on each AOI, gaze duration mean on each AOI, and fixation rate (count/s) [1], [17]. While for the scale for eye-tracking measurements are grouped into two categories, namely temporal scale (measured by time) and spatial scale (measured by space) [18].

- Eye-tracking in learning. The development of information technology in the era of industrial revolution 4.0 has changed the outlook of educators to improve the more innovative learning systems. It is expected to make the learning process effective so that it is easy to be remembered and understood by students. Previous research has succeeded in applying eye-tracking technology to find out the pattern of eye movements on reading distractions that move from text to diagrams [5]. Besides, eye-tracking is also used to determine the multiple choices of science solving strategies made in the form of images that are relevant to the given problem [16]. The result of this study indicates that the visual attention of students who successfully answer correctly is more likely to pay attention to the relevant factors. While students who do not succeed answer questions, visual attention is more often to the questions given. This can be proven from the data fixation which has more correct answers than the wrong answers. From the results of the literature review, (a) the use of the eye-tracking method in understanding the learning process of students becomes a very helpful tool for linking relevant learning outcomes from the learning process that has been applied by educators, specifically related to students' metacognitive abilities in solving chemical problems, (b) before integrating eye-tracking into education studies, researchers must know the steps to analyze eye movements that can affect the metacognitive skills.
• Eye-tracking and metacognitive skills. In the learning process, we are often faced with problem-solving situations that require completion with the right level of metacognitive skills. However, many students are not aware of how to develop metacognitive skills in the learning process and problem-solving. Previous research has explained that the thought process of metacognitive can be seen from eye movement activity [19]. Eye movements contribute to identifying relevant information and help improve thinking skills for processing information during learning [20], [21]. One of the success rates of metacognitive skills based on the results of the analysis of eye movements is when a person could recognize or concentrate on a given task to solve a relevant problem [16]. However, it is difficult to reveal how precise eye movements to improve implicit metacognitive skills[22]. So, before integrating eye-tracking into the education studies, researchers must know the steps in analyzing the right eye movements to improve metacognitive abilities.

In this study, we reviewed empirical studies on eye-tracking in the education field and aimed to describe the use of the eye-tracking method to measure students’ metacognitive skills in chemistry learning. By analyzing relevant papers (80 papers), we expect to disclose the process of using eye-tracking measures students' metacognitive skills in chemistry learning, how to analyze students' metacognitive skills using eye-tracking, whether eye-tracking is effective for measuring students' metacognitive skills in learning chemistry, and what are the advantages and disadvantages of using eye-tracking in measuring student metacognitive skills. The results of the analysis and integration of the obtained information based on the questions used in the review of papers in this study can help build a framework for how the eye-tracking method can inform us about the activities of metacognitive skills in chemistry learning including solving chemistry problems.

3. Method
The literature review in this study comes from various sources with major discussions on students’ metacognitive skills in science especially on chemistry learning and the use of eye-tracking. The method that is used in this study consist of two ways, (1) paper selection and (2) content analysis. The implemented procedure in the paper selection of this study can be grouped into two stages. (1) Pay attention to the keywords of each paper, at least include the keywords such as eye-tracking, the using of eye-tracking, eye-tracking in learning, metacognitive skills, metacognitive skills in chemistry learning, eye tracking and metacognitive skills. The papers that contain these keywords are then further selected, specifically in the field of chemical learning and implicated solving chemical problems. (2) The researcher manually and systematically filtered the titles and abstracts as well as confirmed that the papers that have been selected: (a) are not done on robots, animals, babies or people with special needs, this is because the main focus in this study is about the use of eye-tracking in measuring student metacognitive skills, especially in chemistry learning; (b) discussing the use of eye-tracking in general; (c) discussing the measurement of metacognitive skills using eye-tracking, including in chemistry learning. As far as 80 papers were taken as samples in this review. In these paper reviews conducted by researchers, each investigation or study uses eye-tracking even though presented in one paper will be counted as an independent study.

The content analysis in this study consisted of three stages. (1) The contents of the selected paper are given initial marks based on the topic of discussion to get an explanation of the role of metacognitive skills for students, the relationship of metacognitive skills with 21st century skills, the role of 21st century and metacognitive skills in chemistry learning, the using of eye-tracking, eye-tracking in learning as well as eye-tracking and metacognitive skills. (2) All papers that have been marked from the first stage are further examined to find the answers to the questions that researchers made as problem statements (guiding questions for reviewing papers), regarding the process of using eye-tracking to measure students' metacognitive skills in chemistry learning, analyze the data measured by students' metacognitive skills using eye-tracking, the effectiveness of eye-tracking to measure students' metacognitive skills in chemistry learning, and the advantages and disadvantages of using eye-tracking in measuring students' metacognitive skills. (3) The researcher pursued the
obtained information from the results of the second stage (paper review), so that the core information can be acquired which was discussed in point 4, i.e. the use of eye-tracking for measuring students' metacognitive skills in chemistry learning.

4. Results and discussion
The results of the papers analysis in this study can be illustrated in the Figure 1.

Figure 1 shows to us that there is a relationship between variants of eye movements that are obtained from the use of eye-tracking with the increasing use of metacognitive skills during the learning process [23]. The right range of eye movements when completing a given task, showed an increase in one's thinking ability [24]. This result was reinforced by a study conducted by Ogino [19], that a person who has higher reading focus reflected the difference in metacognitive skills followed by a critical level of reading.

One form of students' metacognitive skills measurement with eye-tracking was through multimedia-based learning by giving assignments in the form of text + images vs. audio + images [25]. Then, each participant filled out the metacognitive skills questionnaire shortly after completing the assignment. Meanwhile, to measure the variance of eye movements with metacognitive skills, the eye-tracking tool was placed below the monitor screen with a distance of the computer screen and students around 60-70 cm. The results of eye-tracking data are analyzed based on a spatial scale (measured by space) which consists of a fixed count on each AOI and a fixation rate (count/s) area of interest (AOI)[26]. Measurement of metacognitive skills with eye-tracking through multimedia-based learning produced two main points, i.e. (1) learning methods that use audio + images rather than text + images and (2) results from observing eye-tracking data with metacognition questionnaires in the form of correlation of visual attention with metacognitive skills. The result of this correlation is followed by a higher number of fixations on the audio + image task.

Besides being analyzed based on spatial scale, the results of eye-tracking data in measuring metacognitive skills can also be analyzed with temporal scale (measured by time) based on the total duration of fixation, average fixation duration, and gaze duration mean on each AOI[16]. Students are asked to complete multiple choices on science questions which were visualized in the form of images that are relevant to the questions given. The results of the analysis of eye-tracking data indicated that someone who can use metacognitive skills in completing a given task will be followed by the number of fixations that have more correct answers than the wrong answers.

Although several studies have explained how the eye-tracking method can be used to measure metacognitive skills in learning including chemistry learning, however, no more in-depth studies related to effective measurement scales are used to measure these metacognitive skills. Also, research in the field of education does not pay attention to the factors that influence the accuracy of the measurement results from the eye-tracking tool such as the distance of the eye-tracking tool with the user, the lighting and the eye-tracking calibration process before the experiment begins.

5. Conclusion
Eye-tracking is an effective method for measuring students' metacognitive skills in chemistry learning since a person's thinking process is based on visual assumptions that are processed into information. Through the use of eye-tracking, it is easier to know the relevant factors that influence the use of
metacognitive skills in learning, including problem-solving, and eye-tracking data can also be a metacognitive tool for reflective self-assessment in student learning. Therefore, using eye-tracking is expected that educators obtain a variety of information that can be used as the basis for developing innovations in learning to help students solve problems presented during and after the learning process as well as to help students reflect on learning and problem-solving they have done.

6. Future studies
At the end of the results of the paper analysis, researchers have an interest in collaborating with other observers of teaching and learning, metacognitive experts, and technology experts especially in eye-tracking to jointly conduct further research on the use of eye-tracking to measure students' metacognitive skills. Since the teaching and learning analysis has been carried out in various ways, including eye-tracking. Eye-tracking allows teachers deeper insights into the learning process and to access new knowledge of how to provide feedback and guidance to learners, and learning researchers utilize eye-tracking methods to comprehensively and systematically describe, investigate and characterize the student learning process including the use of metacognitive skills[2].

Some chemical materials that are considered by researchers to be used as studies in further research regarding the use of eye-tracking to measure students' metacognitive skills in chemistry learning, i.e. chemical bonds [12], chemical equilibrium [11] as well as solubility and its product constant [10]. These chemical materials have been used by researchers in research to measure metacognitive skills in solving chemical problems. Measurements that were made during previous studies [12], [11], [10] have not yet used the eye-tracking method but rather by manually solving the chemical problem questions, and assisted with metacognitive skills questionnaires.

The description of the follow-up research design that will be carried out to this literature review is applying multimedia-based chemical learning with a presentation of chemical problems during the learning process and the end of learning (assessment) in the form of essay questions. Essay questions are made in three types with predetermined chemical material, i.e. in the form of text, images, and audio (separately). Measuring metacognition skills of students using eye-tracking is done during chemical problem solving with three forms of the question and analyzed with spatial and temporal scales. Then the students answered the metacognition skills questionnaire that had been prepared and interviewed the students. The output of this advanced research is expected to provide an overview of the forms of learning offerings and problems that are suitable to increase the use of students’ metacognitive skills so that students’ problem-solving skills that are required by 21st-century skills will be also increased.

References
[1] Lai M, Tsai M, Yang F, Hsu C, Liu T, Lee S W, et al 2013 Educ Res Rev. 10 115
[2] Mike H, Eliot M, Knight B A, Reilly R 2013 Current Trends in Eye Tracking Research (New York: Springer)
[3] Abell S K 2013 Handbook of Research on Science Education [Internet] 1st ed. Routledge; [cited 2019 Jul 17]. Available from: https://www.taylorfrancis.com/books/9780203824696
[4] Rayner K 1998 Eye Movements in Reading and Information Processing: 20 Years of Research. Pyschological Bulletin 124 372
[5] Rayner K 2009 Q J Exp Psychol. (April 2013) pp 37–41.
[6] Land M F, Tatler B W 2009 Looking and Acting: Vision and Eye Movements in Natural Behaviour. (New York: Oxford University Press) p 269
[7] Lai E R, Viering M 2012 Assessing 21st Century Skills: Integrating Research Findings National Council on Measurement in Education p 67
[8] Evangeline C J 2016 Scholarly Research Journal for Humanity Science & English Language 3 4054
[9] Muna K, Sanjaya R E, Syahman, Bakti I 2017 AIP Conf. Proc. p. 020008 Available from: http://aip.scitation.org/doi/abs/10.1063/1.5016001 [cited 2019 Jul 2]
Muna K, Haryani S, Susilaningsih E 2016 Journal of Innovative Science Education 5 19
Muna K 2017 Quantum, Jurnal Inovasi Pendidikan Sains 8 89
Muna K, Fajar K N, Ihsan M 2013 Analisis Kemampuan Metakognisi Siswa Program Akselerasi Pada Materi Ikatan Kimia di SMA Negeri Banjarmasin Laporan Akhir PKM-P pp 1-15
Rickey D, Stacy A M 2000 J Chem Educ. 77 915
Andrew T. Duchowski 2003 Eye Tracking Methodology: Theory and Practice. (London: Springer)
Alemdag E, Cagiltay K 2018 Comput Educ 413
Tsai M, Hou H, Lai M, Liu W, Yang F 2012 Comput Educ. 58 375
Hyönä J, Radach R, Deubel H, Editors 2003. Eye Tracking in Human-Computer Interaction and Usability Research: Ready to Deliver the Promises. (Amsterdam; Boston: North-Holland) p 741
Radach R, Kennedy A 2004 Eur J Cogn Psychol 3–26
Ogino R, Hayashi Y, Seta K 2017. Enhancing Metacognitive Inference Activities Using Eye-movements on One’s Academic Paper in: Workshop Proceedings of the 25th International Conference on Computers in Education. New Zealand: Asia-Pacific Society for Computers in Education pp 482–92
Jarodzka H, van Gog T, Dorr M, Scheiter K, Gerjets P. Learning to See 2013 Learn Instr 25 62
Alemdag E, Cagiltay K 2018 Comput Educ. 125 413
Ogino R, Hayashi Y, Seta K 2018 Enhancing Metacognitive Inference Activities Using Eye-Movements on One’s Academic Paper. J-Stage The Transactions of Human Interface Society pp 501-510
Azevedo R, Aleven V 2013 Eye Tracking as a Tool to Study and Enhance Cognitive and Metacognitive Processes in Computer-Based Learning Environments. (In: International Handbook of Metacognition and Learning Technologies). Chapter 10 p 78.
Susac ANA, Bubic A, Kaponja J, Planinic M, Palmovic M 2014 Int J Sci Math Educ. pp 555–6
Antonietti A, Colombo B, Di Nuzzo C 2015 Learn Media Technol 40 187
Stieff M 2013 Leveraging Eye Tracking Methods for Chemistry Education Research In Michigan State University: Copyright Michigan State University Board of Trustees. (East Lansing, MI 48824) Available from: https://create4stem.msu.edu/event/eye-tracking-mini-conference/1278