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Higher Order Thinking Skills and Visual Representations of Chemical Concepts: A Literature Review

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Abstract
Efforts to assist students in understanding generally abstract chemical concepts are widely done using visual representations as a form of multiple representations in chemistry. This article evaluates and identifies articles from the year (2013-2023) through search engines that provide international services and national journal pages that can be accessed using 4 databases, namely, science direct, eric, google scholar, and crossref. Based on predefined criteria for the use of visual representation in chemistry to improve Higher Order Thinking Skills, 13 relevant articles were obtained. The results of the review show that visual representation can be utilized to train and improve higher-order thinking skills, especially critical, logical, reflective, metacognitive, and creative thinking. Visual representation has also been applied to several approaches or learning models such as Multiple Representation, Particulate Representation, 5R, SWH, Marzano's Taxonomy, Use of Concept Maps, and PcBL.

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INTRODUCTION

Chemistry is frequently seen as challenging by students due to its inclusion of complex concepts and themes (Santos & Arroio, 2016). To understand chemistry comprehensively, there are actually 3 aspects of representation that must be mastered. These aspects are macroscopic aspects (phenomena that can be observed and sensed with the five senses), submicroscopic aspects (the use of diagrams or images that show phenomena at the molecular, atomic, ionic level), symbolic aspects (the use of chemical equations and chemical symbols to describe a phenomenon) (Davidowitz & Chittleborough, 2009). The three representations in chemistry are well recognised as triplet representations (Wiyarsi, Sutrisno, & Rohaeti, 2018).

Representations can support chemistry learning, through the use of representations of submicroscopic phenomena that are difficult to present in the real world can be overcome (Gilbert, Reiner, & Nakhleh, 2008). Representations can visualize the interrelationships between macro, submicro, and symbolic levels on chemical topics. Figure 1 presents an example of presenting phenomena with the triplet representations. Water in a glass that can be seen directly is a macro-level representation, the constituent particles of water in the form of H_2O molecules that cannot be seen directly are presented using submicro-level representations in the form of H_2O molecular images and symbolic levels of H_2O molecular formulas.

Visual representations at the macro, submicro, and symbolic levels in the form of images act as an aid for students, especially at the submicro level which is difficult to imagine, students can find useful help in the multi-representation series provided to facilitate their learning, especially if the concept or content of the material is abstract. Representations can be expressed in both external rand internal representations. External representations consist of what the eye actually sees and is physically available, whereas internal representations are representations that can only be imagined in the mind and are mentally available to each person. The meaning-making of a representation is referred to as visualization (Gilbert, Reiner, & Nakhleh, 2008).

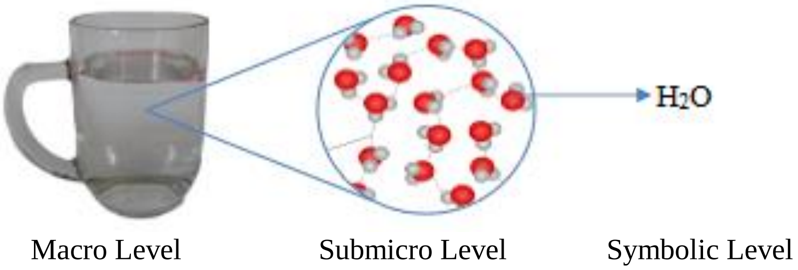

Figure 1. An example of presenting phenomena using visual representations (Chang, 2005)

Chemistry contains many abstract concepts such as symbols, structures, reactions and structured chemical processes. Complex and abstract concepts in chemistry make students think that chemistry is a difficult subject. According to Middlecamp & Kean (1994), the difficulty in studying chemistry is related to the characteristics of chemistry itself which includes, most chemistry is abstract; chemistry is a simplification of the real thing; matter in chemistry is sequential and rapidly developing; Chemistry is not only solving problems consisting of numbers but also must learn chemical facts, chemical rules, and chemical terminology; The material studied in chemistry is numerous. Some of the causes of difficulties that are often experienced in studying chemistry are related to the source of difficulty in studying chemistry.

To facilitate students' understanding of these generally abstract chemical concepts, a presentation of concepts involving multiple representations is needed, one of which uses visual or image-based representations. The abstractness of chemical concepts can be optimized by involving various representations in the chemistry learning process. Visualization is a very important component in teaching chemistry. To gain in-depth chemical knowledge is a challenge for students in understanding the three levels of particulates from several chemical concepts. Chemistry teaching by focusing on visualization such as depicting chemical problems in a pictorial style (graphs, pictures, and tables) can reveal deep understanding as well as deepening unscientific understanding (Habiddin & Page, 2020). Visualization has great potential to stimulate students' HOTS in learning and evaluation as facilitating understanding of concepts by looking at pictures or diagrams students can form a stronger representation of the chemistry concepts being taught.

In solving chemistry problems, the main key is the ability to present scientific phenomena at the macroscopic level (Sunyono, 2015). Chemistry encompasses numerous abstract and intricate concepts, although many individuals possess poor higher-order thinking skills (HOTS), which hinders their comprehension of chemical principles and occasionally leads to mistakes. As a result, chemistry is frequently seen as a challenging discipline (Sirhan, 2007).

Some chemists explain and describe chemical phenomena in terms of three levels of representation: macroscopic, submicroscopic, and symbolic. Treagust et al (2003) stated that chemistry generally consists of three levels which include macroscopic, submicroscopic, and symbolic representations that are combined to strengthen the explanation of chemical concepts. The concept of representation is important in the field of chemistry studies, because can facilitate the learning process. According to Rangkuti (2014) visual representation is an activity to express mathematics ideas in form of diagrams, graphs, and tables.

Arcavi (2003) suggests that visualisation is a cognitive process that involves creating, interpreting, and reflecting upon visual representations such as images, photographs, and diagrams. These representations are used to convey information, facilitate thinking, and foster the development of novel ideas, ultimately enhancing comprehension. Therefore, visualization plays an important role in the thinking process that gives a picture of absrak thinking into concrete. Therefore, visualization becomes an effective tool to explore problems in the learning process of chemistry.

Based on this explanation, it is essential to conduct an in-depth review of relevant literature on chemistry learning using visual multirepresentation to improve students' higher level of thinking. This article provides the findings of a comprehensive literature study on the topic of learning chemistry through the utilisation of visual representations. The articles examined in this work were acquired by conducting a comprehensive review of articles published between 2013 and 2023. Through this literature review, it is expected that chemistry education teachers and researchers gain insight and information about visual representations, and their contribution in improving students' HOTS in chemistry learning.

METHOD

The study employs the Systematic Literature Review (SLR) method, which involves applying specific guidelines to discover and synthesise pertinent research papers and evaluate the existing knowledge on the investigated issue (Xiao & Watson, 2019). The articles obtained in this review literature are taken from online database sources Scopus, ERIC, Google Scholar, and Crossref for the last 10 years namely from 2013-2023 with the keywords used are "Multiple Visual Representation", "Modeling", "Chemistry", and "High Order Thinking Skills".

After searching for the desired keyword terms, researchers read the title and abstract of the article to select articles that meet the following inclusion criteria: 1. Articles about learning using Multiple Visual Representation in chemistry learning; 2. The publication year range of the journal used is 2013-2023 (last 10 years); 3. Article publication must be reputable, accredited, and full text. This research has special criteria in the selection of journals, namely research on the topic of problems related to learning using Multiple Visual Representation in chemistry learning and journals published after 2013, as well as journal names with code A available in Table 1. Shows the remaining 13 articles obtained from the initial search results.

Tabel 1. Articles and Journal of Selection Results

No	Author and Year	Journal code
1	Habiddin & Page, (2020)	A1
2	A Ghani, et al (2016)	A2
3	Baptista, et al (2019)	A3
4	Berg, et al (2019)	A4
5	LaDue, et al (2015)	A5
6	Stephenson & Sadler-McKnight, (2013)	A6
7	Toledo & Dubas (2016)	A7
8	Prilliman (2014)	A8
9	Santos & Arroio (2016)	A9
10	Abdurrahman, et al (2019)	A10
11	Habiddin, et al (2023)	A11
12	Habiddin & Page (2021)	A12
13	Wiyarsi, et al (2018)	A13

The process of searching and selecting articles is described in Table 1. can be seen in Figure 2. prisma detailing identification, eligibility, and included below.

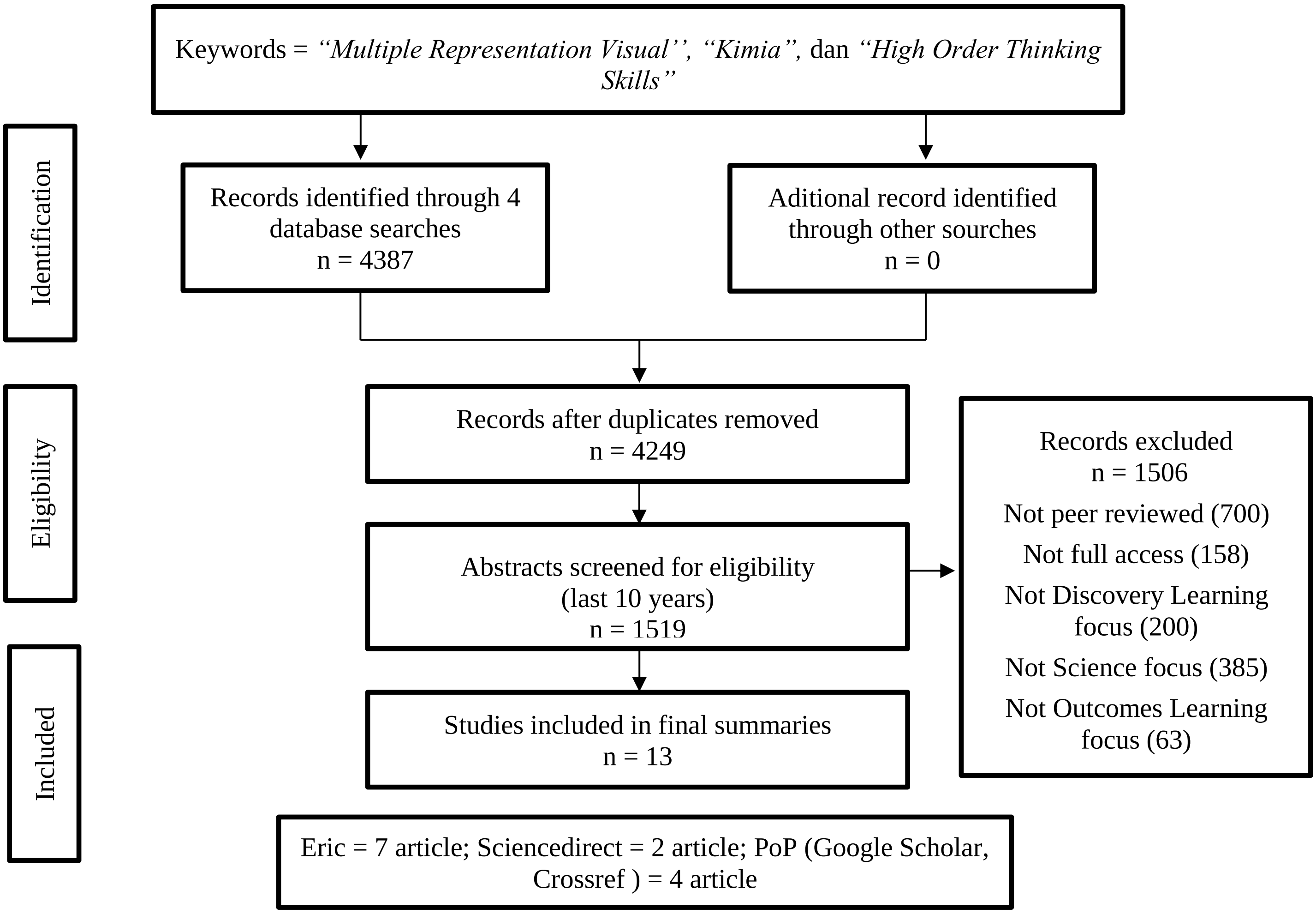

Figure 2. Prism of Article Search and Selection Process

RESULTS AND DISCUSSION

The Use of Visual Representations in Chemistry Learning

Visual representations in chemistry learning have a beneficial effect on students. The research papers gathered through a systematic literature analysis demonstrate the favourable impact of visual representation on enhancing students' higher-order thinking skills (HOTS) in chemistry as illustrated in Table 2. Based on research conducted by Habiddin & Page (2020) states that students' ability to answer HOTS questions must still be trained again and must be familiar with questions with the HOTS type, and it is suggested that enhancing students' HOTS is crucial in all facets of chemistry education. Employing effective teaching and learning strategy can significantly bolster students' HOTS. Additionally, promoting active learning methodologies can further augment the ability. Insufficient mathematical proficiency can lead to errors while attempting to solve HOTS questions. Although students may grasp the underlying concepts, they often make mistakes as a result of inaccurate arithmetic calculations. In these cases, students tend to use numerical operations to solve even simple conceptual questions. Student performance in answering algorithmic questions is better than student performance in answering pictorial questions (Habiddin & Page, 2020).

Chemistry education emphasises the use of three levels of chemical representation to enhance students' comprehension of chemical ideas and prevent misconceptions. This approach enables students to recognise the interconnections between these levels and get a deeper understanding of chemistry. If students understand the concept well, the effort during learning and doing questions is reduced, so that the achievement of learning outcomes can increase and affect student HOTS, and a robust understanding also increases the ability to achieve student self efficacy.

Table 2. Effect of Multiple Representationon Visuals to improve HOTS

No	Author and Year	The Effect of Multiple Representationon Visuals on Students' Critical Thinking
1	Habiddin & Page, (2020)	Investigating students' HOTS using pictorial style questions
2	A Ghani, et al (2016)	Improving students' HOTS using concept maps in laboratory educational activities
3	Baptista, et al (2019)	Help students to develop cognitively by using multiple representations
4	Berg, et al (2019)	Encourage student reflection on the sub-micro in laboratory exercises using representational in animation chemistry
5	LaDue, et al (2015)	See similarities and differences in visual representations of students in chemistry learning
6	Stephenson & Sadler-McKnight, (2013)	Develop students' critical thinking skills using science writing heuristics
7	Toledo & Dubas (2016)	Encourage HOTS students in chemistry learning using Marzano's taxonomy
8	Prilliman (2014)	Apply particulate representations to chemistry learning
9	Santos & Arroio (2016)	Looking at the influence and contribution of representation levels (macroscopic, microscopic, and symbolic) in chemistry learning
10	Abdurrahman, et al (2019)	Apply multiple representation-based LKS to critical thinking skills
11	Habiddin, et al (2023)	Examine the effect of PcBL-based learning on conceptual change
12	Habiddin & Page (2021)	Test the difference between students' ability to answer algorithmic and pictorial type questions
13	Wiyarsi, et al (2018)	Analyze students' creative thinking skills in applying multiple representation approaches

Currently, it is imperative for students to actively engage in the learning process. Hence, it is anticipated that students will actively participate in the learning process by engaging in activities such as posing inquiries, providing answers, and reacting to the learning materials (Nugrahaeni et al, 2017). In addition, student activeness is also seen from their efforts to learn everything according to their will and ability, so that teachers only act as motivators, guides, and facilitators.

Based on research conducted by Habiddin & Page (2020), it shows that students demonstrate superior proficiency in solving algorithmic questions compared to picture-based ones. This is because their lack the ability to discern pertinent information from visual representations such as graphs, diagrams, or tables. The work of Ghani et al (2016) showed a positive development of students' understanding and HOTS towards the concept of electrolysis using concept maps. Research conducted by Santos & Arroio (2016) suggests that chemistry is regarded as a challenging discipline to grasp due to its incorporation of microscopic, macroscopic, and symbolic elements, as well as its reliance on abstract concepts. The development of chemical concepts and the explanation of chemical phenomena rely on a comprehensive grasp of both microscopic and macroscopic levels, which are effectively communicated through symbolic representation. Hence, a comprehensive grasp of chemistry entails the capacity to depict and convert chemical quandaries utilising observable, particulate, and symbolic modes of representation.

Another study conducted by Abdurrahman, et al (2019) suggests that multiple representations learning can improve students' critical thinking compared to conventional learning and students have the potential to answer HOTS type questions easily. Baptista, et al (2019) stated that the use of multiple representations in the development of cognitive structures progresses from pretest to posttest, development is influenced by the way students use multiple representations and utilize the three functions of multiple representations and the students realize that the combination of the three functions allows them to move across levels of representation (macroscopic, submicroscopic, and symbolic), and develop a better understanding. more deeply and structured about concepts related to chemistry. While research conducted by Berg et al (2019) shows that the use of representation in animation chemistry can enhance and encourage reflection of sub-micro level students as well as the relationship between macro and sub-micro levels.

LaDue (2015) suggests that the use of Visual Representations can also improve student learning outcomes in learning biology, chemistry, earth sciences, and physics. While Stephenson & Sadler-McKnight (2013) research suggests that the use of Science Writing Heuristics in the laboratory can improve students' critical thinking, and While the use of Marzano's Taxonomy can also increase students' HOTS in chemistry learning (Toledo & Dubas, 2016). Research conducted by Prilliman (2014) that students respond well to discussions about particulate representations. A significant number of students are enthusiastic about enhancing their conceptual comprehension as it enables them to perceive chemistry as a comprehensive framework for comprehending the natural world, rather than a mere collection of disconnected equations and calculations.

Based on the research of Habiddin et al (2023) in dealing with pictorial representations, there are two challenging problems faced by some students, namely difficulties in extracting relevant information and errors in transforming information extracted from pictorial contexts into chemical behavior. This encourages the development of students' ability to interpret images, graphs and tables so that students can extract valuable information from these representations. While research conducted by Wiyarsi et al (2018) states that the impact of using numerous representations on students' learning. The results of HOTS indicate that the posttest has a greater influence than the pretest. The explanation highlighted that the comprehension of HOTS was not the only aspect that improved. Additionally, there was an enhanced understanding of chemical concepts due to the utilisation of multiple representations. By employing various forms of representation, such as depictions or pictorials, students were able to grasp abstract chemical concepts more effectively. Utilising visual aids in chemistry instruction is crucial to enhance the ability to visualise and comprehend representations.

Treagust & Chandrasegaran (2009) suggest that visual representation-based learning engagement is effective in improving student HOTS, visual representation-based learning activities invite students to understand chemical material both macroscopic, submicroscopic, and symbolic, and provide opportunities for students to formulate and understand chemical material based on three levels of representation so that the level of student understanding of chemical material becomes better.

Application of Visual Representations to Approaches/Models in Chemistry Learning

In the learning process students must be more involved and play an active role. Thus, student activeness is seen from its role in learning such as asking, answering questions, responding, learning something according to their will and ability, so that teachers only act as motivators, guides, and facilitators in the learning process (Nugrahaeni et al, 2017).

The learning process must use various learning models, including chemistry learning in the application of visual representations to increase student activity, interest in learning, and learning outcomes. In addition, the use of various learning models in the application of visual representations is also very important in chemistry learning. The systematic research article in this literature review shows that visual representation has been applied to several approaches/models in chemistry learning. Implementation can be seen in Table 3.

Table 3. Application of Visual Representations to multiple Approaches or Models

No	Author and Year	Approach/Model
1	Habiddin & Page, (2020)	-
2	A Ghani, et al (2016)	Use of Concept Maps
3	Baptista, et al (2019)	Multiple Representation
4	Berg, et al (2019)	5R (Read, Reflect, Recite, Review, and Write)
5	LaDue, et al (2015)	-
6	Stephenson & Sadler-McKnight, (2013)	Science Writing Heuristic (SWH)
7	Toledo & Dubas (2016)	Marzano's Taxonomy
8	Prilliman (2014)	Particulate Representation
9	Santos & Arroio (2016)	Representational levels
10	Abdurrahman, et al (2019)	-
11	Habiddin, et al (2023)	Pictorial Based Learning (PcBL)
12	Habiddin & Page (2021)	-
13	Wiyarsi, et al (2018)	Multiple Representation

Table 3 demonstrates that visual representation is often applied to some particulate representation-based chemistry learning approaches such as research conducted by Prilliman (2014) and Santos et al (2016) began by organising students into small groups to investigate the submicroscopic level of the chemical issue being studied. Furthermore, students are asked to relate the levels of particulates that have been explored with macroscopic and symbolic representations and mathematical calculations. While multiple representation-based learning (Baptista et al, 2019; Wiyarsi et al, 2018) were also asked to be divided into multiple small groups were formed to examine a phenomenon. Subsequently, the students were instructed to establish connections between their observations and the three levels of representation. After that, students discuss in front of the class about the results of observing phenomena associated with the three levels of visual representation.

Visual representation is also applied in 5R approach activities (Read, Reflect, Recite, Review, and Write), this approach can help students more effectively understand, remember information presented through visual representation in chemistry learning (Berg et al, 2019). In addition to the 5R, visual representation is also applied in the Science Writing Heuristic approach, Marzano's Taxonomy, where this approach emphasizes writing activities can help students understand scientific concepts that combine elements of writing and scientific thinking to improve student understanding in the context of visual representation (Stephenson et al, 2013; Toledo et al, 2016). Whereas using concept maps strongly supports the learning of visual representations, concept maps help students organize and connect concepts in the topic of electrolysis chemistry using concept maps to the understanding and ability of HOTS (A Ghani et al, 2016).

In addition to being implemented in the learning approach, visual representation is also implemented using the Pictorial Based Learning (PcBL) learning model. This model consists of 5 learning stages, namely, (opening stage; pictorial trigger; presentation and sharing; verification; closure). The results showed that the PcBL model in dealing with pictorial representation, there are two challenging problems faced by some students, namely difficulties in extracting relevant information and errors in transforming information extracted from pictorial contexts into chemical behavior. This encourages the development of students' ability to interpret images, graphs and tables so that students can extract valuable information from these representations (Habiddin et al, 2023).

CONCLUSION

The results of this review show the importance of involving multiple representations, especially visual representations in the teaching of chemistry to improve students' HOTS. Multiple representation makes the abstraction of chemical concepts more real and easy for students to understand. Thus students' understanding of chemical concepts can increase and students' HOTS impact also increases. Furthermore, including various forms of representation in the learning process might mitigate students' preconceived notions that chemistry is a challenging discipline characterised by abstract ideas. And students can solve problems, build and find a chemical concept in learning independently. Thus, an effective understanding of chemical concepts should integrate visual representation as a tool to stimulate and enhance students' HOTS. Based on research obtained from the results of this review article, that visual representation has been applied to several approaches or models of chemical learning models such as Multiple Representation, Particulate Representation, 5R, SWH, Marzano's Taxonomy, Use of Concept Maps, and PcBL. The results showed that the application of visual representation to several approaches or learning models in student HOTS increased effectively.

According to the findings, it is essential to incorporate visual aids in chemistry education to enhance students' higher-order thinking skills (HOTS) and positively impact their learning outcomes. Teachers should incorporate visual representations in chemistry instruction as they enhance students' comprehension of abstract chemical topics, making them more tangible and accessible. Consequently, students' comprehension of chemical concepts might be enhanced. Furthermore, it can also diminish their preconceived notions of chemistry's complexity.

RECOMMENDATIONS

Recommendations for researchers then need to be analyzed on other visual representations and on other approaches or models to be applied in chemistry learning so as to maximize the learning process.

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