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Chemistry Learning Using Multiple Representations: A Systematic Literature Review

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ABSTRACT The abstractness of the chemistry concept can be understood easily through chemistry learning using multiple representations. This article used the Systematic Literature Review (SLR) method to review eleven articles published from 2012 to 2021 and focused on chemistry learning using various representations. The articles are systematically obtained from the online article database ERIC, Scopus, and SINTA. The purpose of a review is to give information to teachers and researchers in chemistry education about the definition of multiple representations, the influence of multiple representations on chemistry learning outcomes, and how to implement various representations in chemistry learning models or strategies. The review results showed that the definition of numerous representations referred to both three levels of chemical representation and the tetrahedral representation of chemistry. Also, it referred to the use of various media. The influence of multiple representations on chemistry learning outcomes included improving concept understanding, improving performance, reducing mental effort, improving self-efficacy, making better cognitive structures, improving mental models, and reducing misconceptions. Multiple representations have also been implemented in several learning models or strategies such as *Inquiry, Inquiry 5E, Guided Inquiry, Problem Solving, Thinking, Aloud Pair Problem Solving (TAPPS), Problem Posing (PP), Cognitive Dissonance,* and *Multiple Representation Based Learning* (MRL).

Keywords Multiple Representations, Chemistry Learning Outcomes, Learning Models/Strategies

1. INTRODUCTION

Chemistry is one of the branches of natural science which studies the properties of substances, the structure of imports, changes of substances, laws, and principles that describe changes in senses, as well as concepts and theories about it (Effendy, 2016). It can also be interpreted as a science that seeks answers about what, why, and how natural phenomena happen that relate to substances, including structure, composition, nature, dynamics, kinetics, and energetics involving skills and reasoning (Huddle & Pillay, 1996; Chang & Overby, 2011). Chemistry has many abstract and complex concepts, but unfortunately, many learners have limited ability to think abstractly, leading to struggle to understand chemical concepts and sometimes experience misconceptions (Milenković, Segedinac & Hrin, 2014; Nakhleh, 1992). This causes chemistry to be often seen as a difficult subject (Sirhan, 2007).

The chemistry concepts' abstractness can be easily understood by involving multiple representations in the chemistry learning process. Wiyarsi, Sutrisno & Rohaeti, (2018) explained that chemistry learning with multiple representations could be a bridge for learners in understanding chemistry concepts. Widarti, Marfu'ah & Parlan (2019) stated that multiple representations of intermolecular force learning in Organic Chemistry I class could help learners better understand concepts. Domin & Border (2004) also assert that multiple representations can help learners to solve problems related to chemistry concepts. Based on these explanations, it is important to do an in-depth literature review of chemistry learning using multiple representations to understand better the implementation and the influence of involving multiple representations in chemistry learning.

This literature review article presents the results of studies from several articles that focused on chemistry learning using multiple representations. The reports studied in this literature review were obtained through a systematic synthesis of articles from 2012 to 2021. Through this literature review article, it is hoped that teachers and researchers in chemistry education get insights and information about multiple representations, the influence

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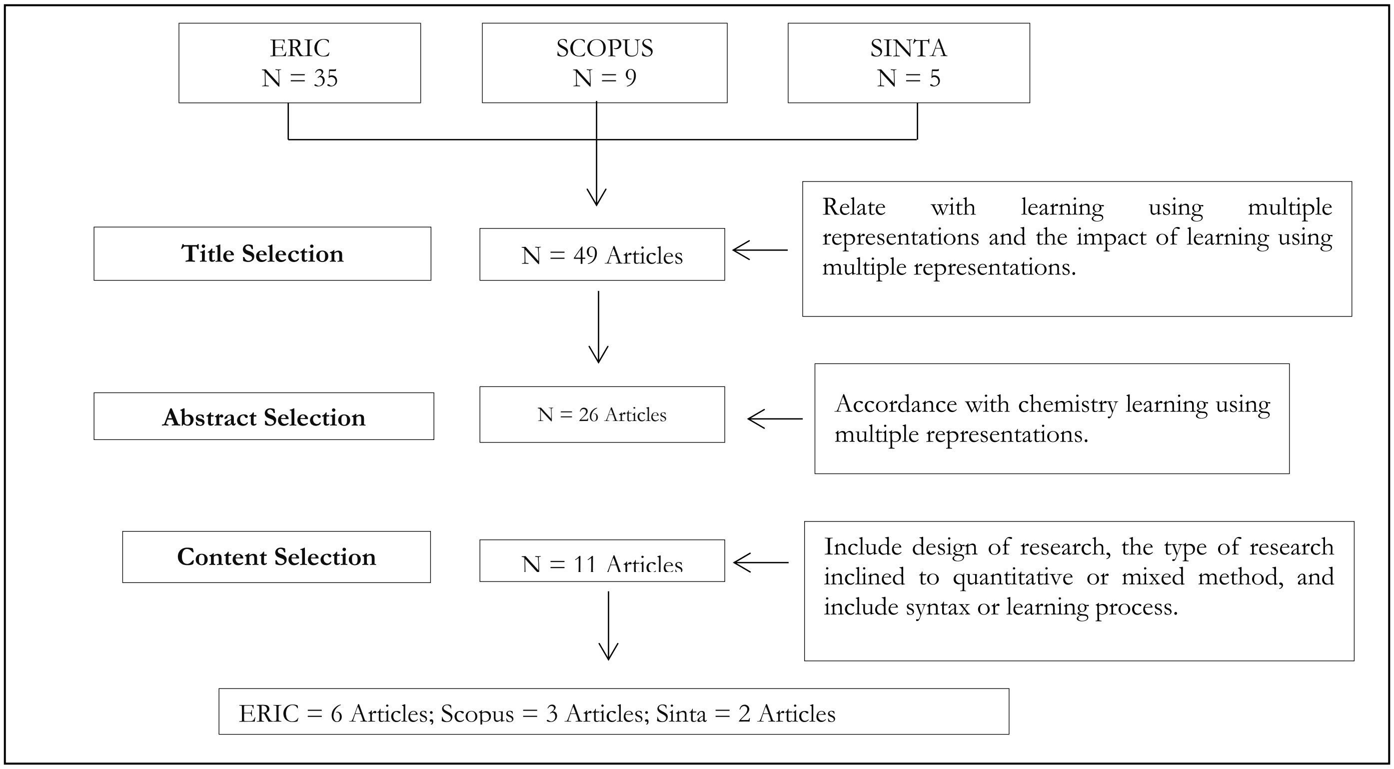

Figure 1 The Process of search and selection articles

of involving multiple representations in chemistry learning, and how to implement them in chemistry learning models or strategies. In addition, it also provides information for researchers in chemistry education about trends and patterns of research over chemistry learning using multiple representations and gives direction for further investigation. The research questions that guided the writing of this article are:

1. What is the definition of multiple representations?
2. How does the effect of multiple representations on the chemistry learning outcomes?
3. How does the implementation of multiple representations on chemical learning models or strategies?

2. METHOD

The method used in this article was Systematic Literature Review (SLR). Xiao & Watson (2019) explain that Systematic Literature Review (SLR) is a literature review method that follows standard rules for identifying and synthesizing relevant research articles and assessing what is known from the studied topic. The articles analyzed in this literature review were obtained by searching the online database ERIC, Scopus, and SINTA (Indonesian Research Database). Literature and analysis were collected from September 30 to December 17, 2021. In this study, the keywords used are "Impact Multiple Representations in Chemistry Learning", "Chemistry Learning with Multiple Representations", "The Effect of Multiple Representations", and "Multiple Representation". After searching for a keyword, the researcher reads the title of the article to select articles that meet the following inclusion criteria: (1) relate to learning using multiple representations and the impact of learning using multiple representations; (2) the year of publication articles from 2012 to 2021; (3) articles from reputable journals that indexed internationally by Scopus or indexed nationally by SINTA.

Based on the article search results, there were 49 titles suitable with inclusion criteria. By then, the abstracts of those 49 articles were analyzed. The result of the abstract analysis was 26 articles following chemistry learning using multiple representations. Meanwhile, the other 23 articles were inappropriate because three articles were numerous representations based on learning for other subjects, and 20 were studies to prove the effectiveness of teaching materials or teaching media that use multiple representations.

Furthermore, all content of 26 articles was read. Based on the results of content readings, 11 articles contained the research design, types of research inclined to quantitative or mixed methods, and incorporate syntax/ learning process. Finally, these 11 articles provided suitable information on what will be discussed. The searching and selection process can be seen in Figure 1.

3. RESULT AND DISCUSSION

3.1 Definition of Multiple Representations

Chemistry is one of the sciences that is often considered difficult for many people because it consists of abstract concepts and topics (Santos & Arroio, 2016). The abstractness of chemistry concepts can be easily understood through the three levels of representation described by Johnstone (1993): macroscopic, submicroscopic, and symbolic. According to Chandrasegaran, Treagust & Mocerino. (2007) and Rahayu & Kita (2010), macroscopic representation relates to observable phenomena or everything that can be seen, touched, and felt by the five senses. Submicroscopic representation relates to the level of particulates such as atoms, ions, and molecules in chemical reactions. Symbolic representation relates to elemental symbols, chemical reaction equations, and chemical formulas. These three levels of representation in chemistry are commonly known as multiple representations (Wiyarsi, Sutrisno & Rohaeti, 2018). Some articles that were obtained systematically as "multiple representations, multiple-level representations, or multiple knowledge representations" referred to the involvement of macroscopic, submicroscopic, and symbolic representations in chemistry learning (Milenković, Segedinac & Hrin, 2014; Supasorn, 2015; Kimberlin & Yezierski, 2016; Derman & Ebenezer, 2020; Tima & Sutrisno, 2018; Widarti, Permanasari, Mulyani, Rokhim & Habiddin, 2021).

Indriyanti, Saputro & Sungkar (2020) use the "multiple representations" word to refer to the tetrahedral representation of chemistry. Mahaffy (2006) explained that tetrahedral representation consists of macroscopic, submicroscopic, symbolic, and the human element as supplementary. The human element emphasizes case studies, active learning, and investigative projects to link school chemistry with daily activities. The word "multiple representations" also refers to the usage of various media to represent a concept or a process. The press mentioned can be in the form of diagrams, equations, tables, text, graphics, animations, sounds, videos, and dynamic simulations (Ainsworth, 2006). The multiple representations which refer to the usage of various media are commonly known as multiple external representations (MERs). In chemistry learning, MERs are regularly integrated with all three levels of chemical representation (macroscopic, submicroscopic, and symbolic) as performed by Baptista, Martins, Conceição and Reis (2019), Sunyono & Meristin (2018), and Priyasmika (2021).

Based on the explanation above, the definition of multiple representations in chemistry learning refers to the involvement of three levels of Johnstone representation (1993) or tetrahedral representation of Mahaffy (2006). In addition, the definition of multiple representations also refers to the involvement of various media in the learning process (Ainsworth, 2006). Although there is a definition of multiple representations that refers to the use of various media, in chemistry learning, these different media are often integrated with macroscopic, submicroscopic, and symbolic representations to make it easier for learners to understand chemistry concepts.

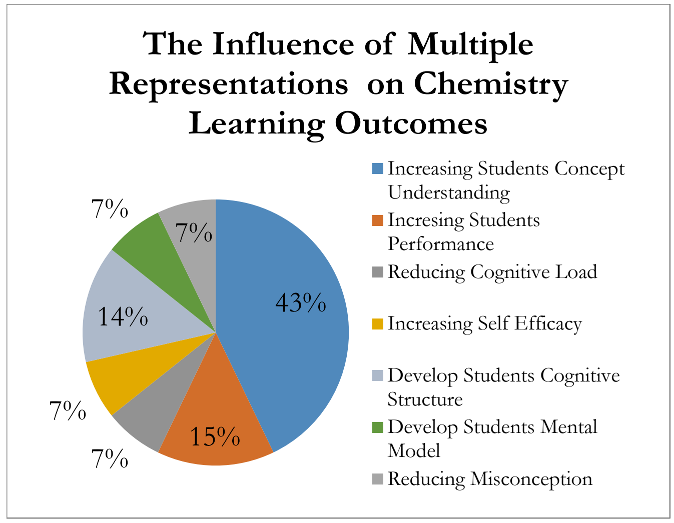

Figure 2 Summary of the influence of multiple representations on chemistry learning outcomes

3.2 The Influence of Multiple Representations on Chemistry Learning Outcomes

The involvement of multiple representations in chemistry learning positively impacts learners. The research articles obtained systematically in this literature review showed some positive influences of multiple representations on the learning outcomes of several chemistry topics, as table 1 shows the influences of multiple representations on the learning outcomes of several chemistry topics

The influences of multiple representations on the learning outcomes are summarized in Figure 2. Based on Figure 2, the greatest influence of multiple representations on chemistry learning outcomes is improving learners' concepts and understanding. A statistical result from several articles showed that the impact of the posttest was higher than the results of the pretest. It explained that understanding concepts increased because it involved multiple representations in chemical learning (Bridle & Yezierski, 2012; Supasorn, 2015; Kimberlin & Yezierski, 2016; Sunyono & Meristin, 2018; Widarti, Marfu'ah & Parlan, 2019; Indriyanti, Saputro & Sungkar 2020). Learners' understanding of concepts can increase as multiple representations become the bridge for learners to understand the abstract concepts of chemistry that require depiction (Wiyarsi, Sutrisno & Rohaeti, 2018; Widarti, Marfu'ah & Parlan, 2019).

Chemistry learning, which highlights three levels of chemistry representation, helps learners see the relationships between the three levels of chemistry representation to understand the concept better afterward. When learners understand the concept well, their mental effort (cognitive burden) during working on problems is

Tabel 1 The influences of multiple representations toward the learning outcomes of several chemistry topics

No	Research and Year	Topic	The influences of Multiple Representations Toward the Learning Outcomes
1	Bridle and Yezierski (2012)	Particulate Nature of Matter	Improve the understanding concepts of learner about Particulate Nature of Matter
2	Milenkovic et al. (2014)	Inorganic Reaction	Improving performance of learner Reducing mental effort of learner
3	Supasorn (2015)	Galvanic Cells	Improve the understanding concepts of learner about Galvanic Cells improving mental models of learner about Galvanic Cells
4	Kimberlin and Yezierski (2016)	Stoichiometry	Improve the understanding concepts of learner about Stoichiometry
5	Sunyono and Meristin (2018)	Chemical Bonding	Improve the understanding concepts of learner about Chemical Bonding
6	Baptista et al. (2019)	Saponifikasi Reaction	Cognitive structures of learner better than before
7	Derman and Ebenezer (2020)	Physical and Chemical Change	Cognitive structures of learner better than before
8	Indriyanti et al. (2020)	Mole Concept	Improve the understanding concepts of learner about Mole Concept
9	Tima and Sutrisno (2018)	Chemical Equilibrium	Improve the understanding concepts and Self Efficacy of learner about Chemical Equilibrium
10	Widarti et al. (2021)	Volumetric Analysis	Reducing misconceptions about Volumetric Analysis on learmer
11	Priyasmika (2021)	Chemical Equilibrium	Improving learning outcomes about Chemical Equilibrium of learner

reduced, so their performance (achievement or learning outcomes) can be improved (Milenković, Segedinac & Hrin, 2014; Priyasmika, 2021). A good understanding of concepts also increases learners' self-efficacy (Tima & Sutrisno, 2018). Self-efficacy can be interpreted as the confidence of learners in working on problems. Involving multiple representations in chemistry learning can also reduce misconceptions that occur in learners when using cognitive dissonance strategies. Misconceptions learners can reduce because integrating multiple representations in cognitive dissonance strategies allows learners to discover concepts, connect new concepts with existing knowledge, and solve problems related to the concepts learned (Widarti, Permanasari, Mulyani, Rokhim & Habiddin, 2021).

Multiple representations also affect the development of a better cognitive structure for learners. It is evidenced by the pretest-posttest results of several articles using WAT (Word Association Test). When the posttest was conducted, learners could write more response words and connect response words compared to the pretest. Differences in pretest and posttest results indicated that the cognitive structures in learners were developed. Multiple representations allow learners to build a deeper and more structured understanding of concepts, so the cognitive structure of learners creates for the better (Derman & Ebenezer, 2020; Baptista, Martins, Conceição

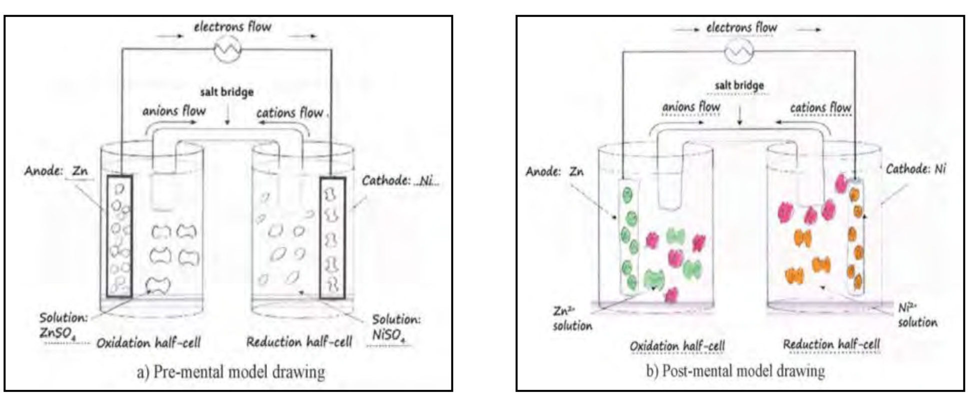

Figure 3 Students' pre and post mental model

and Reis, 2019). Besides influencing the development of cognitive systems, multiple representations can also improve learners' mental models (Supasorn, 2015). It is evidenced by the higher post-model mental score of learners than the pre-model mental score. The improvement of the mental model of learners can also be observed in Figure 3.

Based on Figure 3, the pre-mental model of learners was correct in drawing the oxidation half-cells where there are Zn atoms in the anode and Zn^{2+} ions in the solution. However, learners were still incorrect in drawing the reduction half-cells with Ni^{2+} ions in the cathode and Ni atoms in the solution. In the post-mental model, learners correctly drew the reduction half-cells with Ni atoms in the cathode and Ni^{2+} ions in the solution. The increasing mental model of learners resulted from learning with multiple representations, which provided a learning experience for learners to go through three levels of chemistry representation. Thus, initially, learners only have macroscopic and symbolic understanding to achieve a submicroscopic understanding (Supasorn, 2015).

3.3 The Implementation of Multiple Representations on Chemistry Learning Models / Strategies

Nowadays, learners must be more involved in the learning process. Therefore, the Learners are expected to play an active role in the learning process. Thus, the activeness of learners is reviewed from their role in learning, such as asking, answering questions, and responding (Nugrahaeni, Redhana & Kartawan, 2017). In addition, the activeness of learners is also reviewed from their efforts to learn everything on their will and ability, so the teacher or educator only acts as motivators, guides, and facilitators.

Currently, c hemistry learning uses various learning models or strategies to improve learners' activeness, learning interests, and learning outcomes. Besides using various learning models or strategies, implementing multiple representations is essential in chemistry learning, considering that multiple representations can positively influence learners, as previously described. The systematic research articles in this literature review showed that multiple representations had been implemented on several models or strategies in chemistry learning. The implementation of multiple representations on several models or strategies can be seen in Table 2.

Based on table 2, it can be seen that multiple representations are often implemented on chemistry learning-based inquiry. For example, the inquiry learning-based multiple representations conducted by Bridle & Yezierski (2012) and Kimberlin & Yezierski (2016) begin by asking learners who have been divided into groups to explore the particulate level (submicroscopic) of the topic studied. Furthermore, students engaged in practicum activities were then asked to connect the level of particulates that have been explored with macroscopic and symbolic representations and mathematical calculations (specifically stoichiometric topics). Meanwhile, inquiry learning-based multiple representations conducted by Milenković, Segedinac & Hrin (2014), Baptista, Martins, Conceição and Reis (2019), and Derman & Ebenezer (2020) begins by asking learners who have also been divided into groups to observe a phenomenon or experiment. Then, they were asked to link their observations to submicroscopic and symbolic levels. Afterward, they were asked to explain phenomena or experiments observed macroscopically, submicroscopically, and symbolically in class discussions. The results showed that implementing multiple representations in inquiry learning can improve learners' conceptual understanding. In addition, some articles explain that implementation of multiple representations in inquiry learning can develop better cognitive structures of learners.

Multiple representations also are implemented in the 5E inquiry learning activity (Suparson, 2015). In this case, the learning activity of the 5E inquiry is assisted by a simple practicum combined with a kit model on electrochemical topics. The learning process consists of five stages, namely:

Tabel 2 The implementation of multiple representations on several models or strategies

No	Research	Learning Models/Strategies
1	Bridle and Yezierski (2012)	Inquiry
2	Milenkovic et al. (2014)	Inquiry
3	Kimberlin and Yezierski (2016)	Inquiry
4	Baptista et al. (2019)	Inquiry
5	Derman and Ebenezer (2020)	Inquiry
6	Supasorn (2015)	Inquiry 5E
7	Priyasmika (2021)	Guided Inquiry
8	Tima and Sutrisno (2018)	Problem Solving
9	Indriyanti et al. (2020)	Thinking Aloud Pair Problem Solving (TAPPS) Problem Posing (PP)
10	Widarti et al. (2021)	*Cognitive Dissonance*
11	Sunyono and Meristin (2018)	*Multiple Representation Based Learning* (MRL) / SiMaYang

(1) *engagement*, where learners are involved in scientific questions related to the topics; (2) *exploration*, in which learners are asked to explore and collect data to answer questions through the planning and implementation of experiments; (3) *explanation*, in which learners are asked to formulate explanations based on data and scientific knowledge to answer questions; (4) *elaboration*, in which learners are required to explain, expand, connect, and apply their macroscopic and symbolic findings in experiments to the submicroscopic level through interaction with the kit model; (5) *evaluation*, in which learners are involved in the evaluation of understanding through group and class discussions along with demonstrating the kit model on experimental concepts. The results showed that implementing 5E inquiry learning assisted by a simple practicum combined with the kit model can improve the conceptual understanding and mental model of learners.

Besides 5E inquiry, multiple representations are also implemented in guided inquiry learning. For example, Priyasmika (2021) implements multiple representations (macroscopic, submicroscopic, and symbolic) in guided inquiries at the exploration and concept formation stage. At that stage, learners can process information through investigations related to the presented representations, so their understanding of concepts becomes better. The results showed that implementing multiple representations in chemistry learning with guided inquiry models can improve learners' understanding of concepts and learning outcomes. This is in line with research conducted by Pikoli (2020), where chemistry learning using guided inquiry models with multiple representations can improve the understanding of learners' concepts so that misconceptions that occur in learners can be reduced.

Articles that discuss the implementation of multiple representations in inquiry learning that have been described above, when viewed from the methodology, most of these articles use pre-experimental and quasi-experiment quantitative research methods. When studying the effectiveness, the most effective implementation of multiple representations in inquiry learning is carried out by Milenković, Segedinac & Hrin (2014). This is because Milenković, Segedinac & Hrin (2014) use pretest-posttest control group research designs, while others use one group pretest-posttest research designs. The method of the pretest-postest control group showed the existence of a control class for comparison. So, the effectiveness of treatment is more tested, and the results can be generalized.

Meanwhile, the one-group pretest-posttest research design has not shown the existence of a control class for comparison. So, the effectiveness of the treatment is still doubtful and untested. In addition, the research results due to treatment are still assumptions that need to be followed up again and cannot be generalized.

Besides the inquiry learning model, multiple representations are also implemented in the problem-solving model, as done by Tima & Sutrisno (2018). The problem-solving learning process integrated with multiple representations consists of four stages: (1) *understanding the problem*. At this stage students are asked to read and understand issues about chemical equilibrium that contain macroscopic, submicroscopic, symbolic, and mathematic aspects; (2) *devising a plan*, at this stage students identify chemical equilibrium based on multiple representations and find a way to solve problems from the source of books; (3) *carrying out the plan*, at this stage students, answer all issues of chemical equilibrium in the worksheet which contains macroscopic, submicroscopic, symbolic, and mathematical aspects; (4) *looking back*, at this stage students were asked to review the answers and match them with the sourcebooks. The results showed that chemistry learning using problem-solving models with multiple representations made students more understand concepts. So, their cognitive learning outcomes and self-efficacy became high. This is in line with the results of Domin & Bodner's (2012) study which showed that the implementation of multiple representations in problem-solving could improve the understanding of learners so that they can solve problems in organic chemistry.

Indriyanti, Saputro & Sungkar (2020) implemented multiple representations in two learning models, namely the Thinking Aloud Pair Problem Solving (TAPPS) model and the Problem Posing (PP) model. The multiple representations implemented in both models are multiple tetrahedral representations. Learning activities in TAPPS and PP classes begin with teachers reminding learners of the topics learned last week. Then the teacher gives illustrations about phenomena in the environment and provides a stimulus to calculate the number of particles that are very small and cannot be seen with the naked eye or microscope. Furthermore, TAPPS and PP classes' activities are different. In TAPPS classes, teachers give two problems to each group to solve. While in the PP class, each group is given the same two grids to build two issues (questions), then the completed questions are exchanged with other groups to be solved by that group. The results showed that TAPPS and PP classes had higher posttest scores than pretests, meaning multiple representations, especially tetrahedral representations implemented in learning, can improve the understanding concepts of learners in both classes. However, the understanding of the concept of learners in PP classes was higher than in the TAPPS model. It was because the atmosphere of TAPPS class discussion was passive and skewed one way compared to PP classes.

The implementation of multiple representations in learning can be combined with cognitive dissonance strategies to reduce learners' misconceptions, as done by Widarti, Permanasari, Mulyani, Rokhim & Habiddin (2021). Cognitive dissonance is one of the strategies for creating cognitive conflict (Lee et al., 2003). The learning syntax of cognitive dissonance strategies are: (1) invites the initial knowledge of learners; (2) create cognitive dissonance; (3) implements new knowledge and feedback; (4) reflects; and (5) closing. Cognitive dissonance strategies combined with multiple representations (macroscopic, submicroscopic, and symbolic) in images, curves, and videos can raise questions that motivate students to try to understand and find answers. So, there is understanding concepts change of learners towards clear understanding. The results showed that cognitive dissonance strategies combined with multiple representation-based learning could increase the mastery of learners' concept concepts. In addition, it can reduce misconceptions in learners.

Aside from being implemented in learning models or strategies, multiple representations are also developed into learning models. For example, multiple Representation Based Learning (MRL), called SiMaYang, is a learning model developed by Sunyono in 2013. This model consists of four learning phases: orientation, exploration-imagination, internalization, and evaluation (Sunyono, Yuanita & Ibrahim, 2015). The results showed that the MRL model could improve the mastery concepts of learners and problem-solving abilities, especially for learners with medium and low initial abilities (Sunyono & Meristin, 2018). In addition, the MRL model also effectively optimizes learners' imagination skills so their ability to think and argue to solve problems can increase.

Based on the above, it can be observed that multiple representations have been implemented in several chemistry learning models or strategies such as Inquiry, Inquiry 5E, Guided Inquiry, Problem Solving, Thinking Aloud Pair Problem Solving (TAPPS), Problem Posing (PP) and Cognitive Dissonance. Multiple representations are also developed into learning models, namely Multiple Representation Based Learning (MRL) or the SiMaYang learning model. The results of implementing multiple representations on such learning models or strategies mostly increased mastery or understanding of concepts of learners, and reviewed from the results of the pretest-posttest, models or methods integrated with multiple representations mostly increased posttest value. It is indicated that each model or system combined with multiple representations effectively improves learners' mastery or understanding of concepts.

CONCLUSION

Based on studies from the articles obtained systematically, the definition of multiple representations refers to the involvement of both three levels of chemical representation and the tetrahedral representation of chemistry. It can also refer to various media, but these media are used to integrate chemical representations (macroscopic, submicroscopic, and symbolic). The involvement of multiple representations in chemical learning has a positive influence, including improving understanding of concepts, improving performance, reducing mental effort (cognitive load), improving self-efficacy, making cognitive structures develop for the better, and improving mental models, and can reduce misconceptions. Based on the study, it was also obtained information that multiple representations have been implemented in several chemical learning models or strategies such as Inquiry, Inquiry 5E, Guided Inquiry, Problem Solving, Thinking Aloud Pair Problem Solving (TAPPS), Problem Posing (PP), Cognitive Dissonance, and Multiple Representation Based Learning (MRL). The results showed that implementing multiple representations in some learning models or strategies effectively improved learners' mastery or understanding of concepts.

Based on the results of the article review that has been done, it is essential to involve multiple representations in chemical learning so that students learning outcomes can increase. Teachers should involve multiple representations in chemistry learning because, through multiple representations, the abstractness of chemistry concepts will become more real and easier to understand for learners. As a result, their understanding of chemistry concepts can increase, and the impact of their learning outcomes can also increase. In addition, involving multiple representations in learning can reduce learners' assumptions about chemistry as a difficult subject. The suggestion for further research is to implement multiple representations on other models or strategies that have not been mentioned or make modifications for integrating multiple representations in the models or strategies that have been presented previously. Future research may also implement Mahaffy tetrahedral representations on models or strategies that still use Johnstone multiple representations.

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