Kashihara, A. et al. (Eds.) (2024). Proceedings of the 32nd International Conference on Computers in Education. Asia-Pacific Society for Computers in Education

An Implementation of Augmented Reality in Guided Inquiry-Based Learning for Enhancing Primary Students' Mental Models in Science

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Abstract: Augmented reality (AR) is increasingly recognized as an essential tool in science education by providing interactive and immersive experiences that make complex concepts more concrete and tangible. This is particularly important for primary students, who must establish precise mental models in order to understand science concepts including the states of matter. To accomplish meaningful learning, this is essential to understand both the macroscopic properties and the microscopic structures. Consequently, this study examines the effect of AR in guided inquiry-based learning on the conceptual understanding and mental models of primary school students who are studying the states of matter. The study was conducted with 46 fourth-grade students, utilizing AR to facilitate interactive learning experiences in science classroom settings. A paired samples t-test was performed to analyze students' conceptual understanding. In addition, mental models of states of matter were analyzed by inter-rater reliability techniques. The findings suggested that when effectively integrated AR into inquiry-based learning frameworks, this learning can play a crucial role in enhancing students' conceptual understanding and their mental models, bridging the gap between observable and molecular level in the state of matter concept. Lastly, this study provided suggestions for future research and implementation of AR in guided inquiry-based learning science education.

Keywords: Augmented reality, Inquiry-based learning, States of matter, Mental model

1. Introduction

In traditional science education, one of the persistent challenges has been the effective visualization of complex scientific concepts, particularly in disciplines such as physics and chemistry. In chemistry, where students are often required to analyze and discuss natural phenomena through symbolic representations, the abstract nature of matter-related concepts poses a significant learning barrier (Gilbert, 2010). Research had indicated that visualization tools, including simulations and animations, can play a crucial role in enhancing students' understanding of these abstract concepts (Belford & Moore, 2016). In response to these challenges, educational curricula have increasingly integrated inquiry-based learning approaches. These approaches aim to actively engage students in hands-on exploration and to facilitate the construction of knowledge through direct interaction with scientific phenomena.

With the rapid advancement of educational technologies, many researchers have integrated various tools into science education to enhance student learning experiences. Technologies such as computer simulations, microcomputer-based laboratories, augmented reality, and digital games have been successfully employed in classrooms, leading to significant improvements in students' understanding and engagement (Hwang & Wu, 2014). These tools offer interactive and immersive learning environments, enabling students to engage in experimentation and observation of scientific phenomena in ways that were not accessible in traditional classroom settings. Especially augmented reality, the integration of augmented reality (AR) technology in education has rapidly advanced, driven by the proliferation of personal mobile devices, which have increased accessibility while reducing costs (Garzón & Acevedo, 2019). AR provides students with immersive learning experiences by seamlessly blending real-world and virtual elements (Akçayir & Akçayir, 2017). Likewise, Chen and Liu (2020) used augmented reality in chemistry class, This study has been demonstrated to significantly improve students' motivation and engagement, leading to enhanced learning outcomes in subjects such as chemistry, where the ability to visualize molecular structures and reactions is essential. Consequently, this technique serves as an effective means of enhancing student engagement in learning activities (Wojciechowski & Cellary, 2013; Wu, Lee, Chang, & Liang, 2013).

Among these approaches, researchers have been combining inquiry-based learning with technological improvements to create more effective learning environments. Inquiry-based learning is an educational method that promotes active student participation in the learning process through the exploration and investigation of real-world problems and questions (Anderson, 2002; Buck et al., 2008). For instance, researchers demonstrate that inquiry-based augmented reality has been implemented in science learning activities, which has contributed to positive learning experiences and the development of a positive learning attitude among students (Rosenbaum, Klopfer, & Perry, 2007), learning achievement, and their motivation (Ching, Yang, & Hwang, 2014).

Based on the research principle, student learning is enhanced when visuals and the related text are presented together rather than separately (Mayer, 2001). Thus, the objective of this study is to promote the use of augmented reality (AR) with guided inquiry-based learning, specifically by enabling primary students to interact with and visualize 3D models in real-time. This approach is designed to facilitate the development of accurate conceptual understanding and mental models regarding the concepts of states of matter in science classes.

2. Research Relevant

2.1 The Role of Augmented Reality in Science Education

Augmented reality (AR) is a kind of technology which dynamically overlaps digital resources with a real-world environment (Mejías Borrero & Andújar Márquez, 2012). Azuma (1997) defined AR as a system that possesses three key features: the integration of actual and virtual elements, real-time interactivity, and three-dimensional registration. The integration of AR technology, which overlays digital content onto the physical world through devices such as smartphones and tablets, has been thoroughly examined and recorded by many researchers. Various research shows that augmented reality improves both students' attitudes towards studying and their cognitive growth. For example, Chen and Liu (2020) study examines the effects of incorporating Augmented Reality technology into a chemistry classroom for ninth-grade students with the goal of improving their comprehension of chemical elements and processes. The findings suggest that students who engaged in interactive augmented reality activities had notable enhancements in their comprehension of concepts and interest in real-life scenarios, in comparison to those who were exposed to conventional demonstration-focused learning. The Mancosa iTEACHlab was integrated Augmented Reality into science education, specifically in topics relating to the human body. This study explored the utilization of both marker-based and marker-less augmented reality systems to enhance students' learning experiences. It emphasizes the ability of AR to make abstract scientific concepts attainable and engaging, ultimately leading to improved student motivation and understanding of the subject matter (Mbonye & Ebrahim, 2022).

The integration of augmented reality into inquiry-based learning in science education establishes an immersive educational environment in which students can engage with virtual representations of scientific concepts, fostering active exploration and facilitating increased understanding through hands-on, exploratory activities (Cheng & Tsai, 2013). Chang, Wu, and Hsu (2013) effectively combined mobile augmented reality technology with educational inquiry activities focused on socioscientific themes. The result was that ninth-grade students greatly improved their understanding of science concepts. Chiang, Yang, and Hwang (2014) implemented a mobile learning system that utilized augmented reality to improve the academic performance and motivation of fourth-grade students in natural science inquiry activities. The results indicated that the augmented reality technique has a significant positive impact on students' learning outcomes and motivation when compared to traditional approaches, particularly in the areas of attention, relevance, and confidence. Furthermore, the use of augmented reality in an inquiry-based physics laboratory course evaluates its effects on cognitive load and conceptual knowledge acquisition. The study found that AR can enhance engagement and offer immersive learning experiences (Kapp et al., 2011).

2.2 Students' Mental Models in Science Learning

According to Constructivist theory, knowledge cannot be simply transmitted from teacher to student but must be actively constructed by students through personal exploration. This is especially evident in the understanding of the states of matter, where students experience difficulties in conceptualizing both macroscopic properties, such as shape and volume, and microscopic phenomena, such as particle motion and energy (Massalha, 2015). Developing accurate mental models is crucial in fostering deep learning, especially in scientific domains, as these models enable students to bridge abstract concepts with real-world applications.

For instance, In chemistry, Mental models facilitate the understanding of scientific concepts by allowing students to manipulate and visualize information at various levels of representation, including the macroscopic, molecular, and symbolic levels. Suit and Srisawasdi (2013) used computer simulations to improve students' understanding of concepts by enabling them to visualize and manipulate information at both the molecular and macroscopic levels. Likewise, The utilization of multi-touch simulations in science education has the potential to substantially improve students' mental models by offering interactive and engaging learning experiences. Students are able to better understand the subject matter by visualizing complicated scientific concepts through these simulations, which in turn facilitate the development of more precise mental representations (Marhan et al., 2021).

Moreover, Hali et al. (2017) investigates the impact of a problem-solving-based learning model that incorporates many models on students' mental modeling ability (MMA) in understanding physics ideas, namely the kinetic theory of gases. This study provides evidence that students' mental modeling ability (MMA) improves significantly when they are exposed to this instructional technique. Specifically, students transition from low to medium or high mental modeling ability categories, suggesting the effectiveness of this strategy in promoting a deeper conceptual knowledge of physics. According to Marhan et al. (2012), children's understanding of the technological world is enhanced by their ability to construct and refine their mental models through interaction with digital devices. Similarly, Ponners and Piller (2019) illustrate that augmented reality is a powerful tool for enhancing elementary students' mental models of science and the role of scientists, emphasizing AR's ability to shape students' perceptions and deepen their conceptual understanding. The research suggests that the integration of AR into science education has the potential to greatly improve students' attitudes toward science and promote a greater level of engagement with scientific skills and practices.

3. An augmented Reality about States of Matter Concepts

This study developed an augmented reality tool designed to enhance students' understanding of the states of matter. The tool features three distinct models that visually depict the molecular structure of water across different states—solid, liquid, and gas. These models are accompanied by dynamic animations. As shown in Figure 1 (left), markers are used to trigger the AR experience. For example, states of matter cards consist of the ice marker, water marker, and steam marker are placed on a card. In addition, additional shape markers designed to match with the states of matter cards, providing a deeper study of matter properties. On the right side of figure 1, a user scans an ice marker card using the "MATTER" application on an Android tablet, which displays a 3D model of the ice molecule, allowing for a more interactive exploration of the concept.

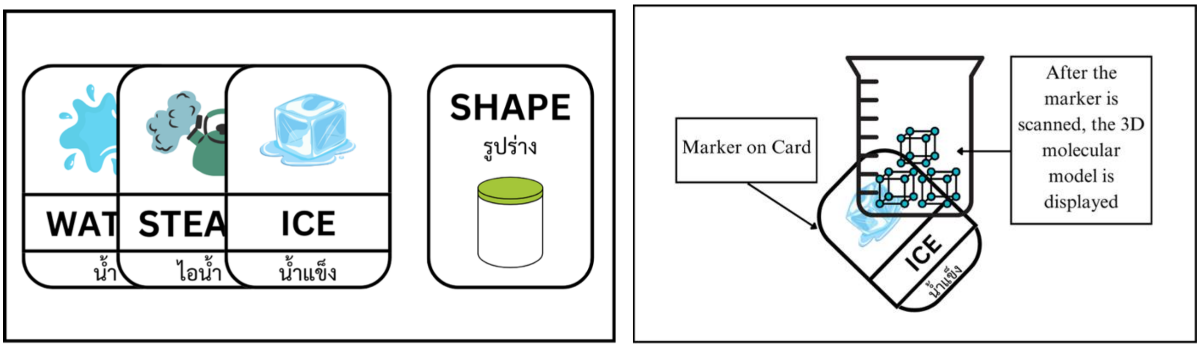

Figure 1. Illustrate designed marker on cards (Left) and example of 3D augmented molecule for science class (Right).

The "MATTER" AR tool is composed of two key elements: the first demonstrates the arrangement of molecules in the solid, liquid, and gas states, while the second focuses on the unique properties of each state. Through AR technology, students can visualize molecular behavior, gaining insights into how molecules shift during phase changes. As illustrated in Figure 2, the AR application allows students to observe molecular arrangements in different states of matter. Furthermore, animations display how molecules move and reorganize as matter changes shape, offering an interactive and intuitive learning experience.

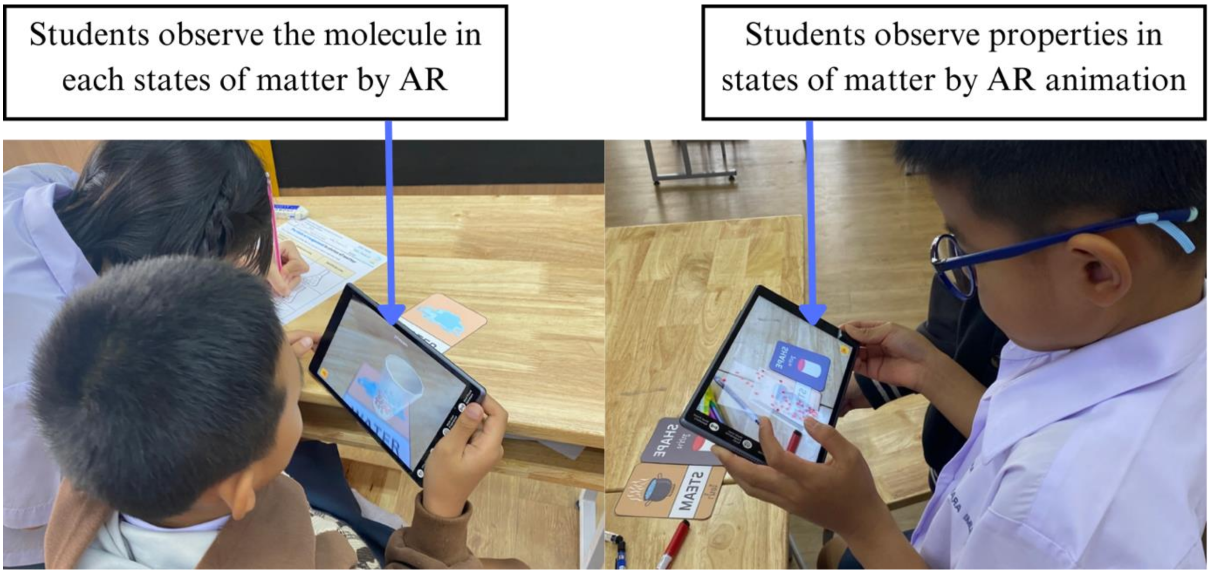

Figure 2. Demonstrated the example augmented reality about states of matter concept.

4. Research Methodology

4.1 Participants

The participants in the study were 46 fourth-grade students, consisting of 20 males and 26 females. For this research, participants of primary school from a school located in the northeastern region of the country, ranging in age from 9 to 10 years old, were selected to participate in the part. They had experienced in augmented reality and had proficiency in using computers and digital devices. Furthermore, they never instructed on the concepts of states of matter in science classes prior to participating in this study. Before doing the experiment, the students were administered a pre-test to evaluate their understanding of important topics and mental models.

4.2 Research Instruments

This study comprised the two main research tools to investigate the students' understanding and mental models. The first research instrument consists of a cognitive concepts test with five multiple-choices and three open-ended questions. These questions were particularly created to assess students' understanding of essential ideas related to the states of matter concepts. The second instrument is a mental models test, which consists of three open-ended parts (solid, liquid, and gas). This test focuses on examining students' mental models, particularly their ability to conceptualize the arrangement of molecules in the three states of matter. These instruments are designed to enable students to construct mental models, encompassing both observable representations (visible phenomena) and molecular representations (conceptual entities), along with detailed explanations to clarify the underlying concepts as show in Figure 3.

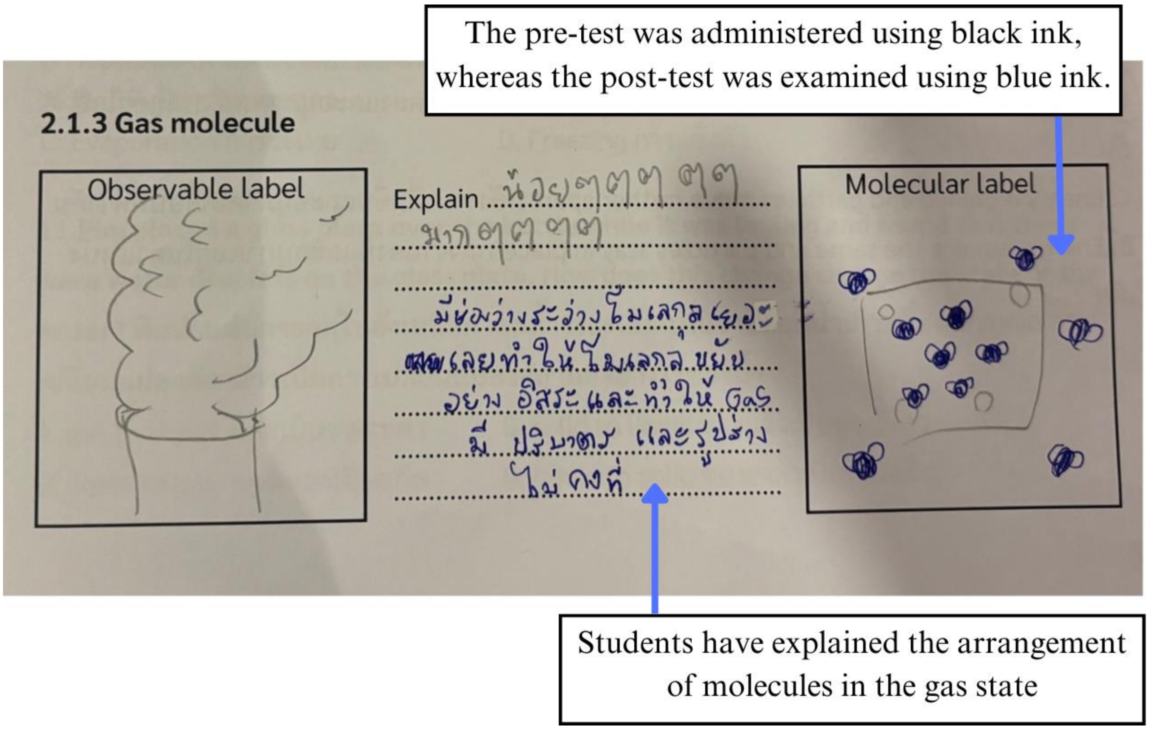

Figure 3. Example of a student’s mental models.

4.3 Data Collection

The experiment began with a 30-minute pre-test designed to evaluate students' existing conceptual understanding and their mental models of solid, liquid, and gas states. Students were asked to complete a pre-test conceptual understanding and mental model regarding the molecules of solid, liquid, and gas to evaluate their basic knowledge before the learning activity. Following this, the students have engaged in an AR in guided inquiry-based learning activity consist of three phases: pre-Interacting, interacting, and post-interacting with a total duration of 150 minutes. In this study, the learning content is based on the concept of states of matter, which is included in the science course. Figure 4 shows the experimental procedure.

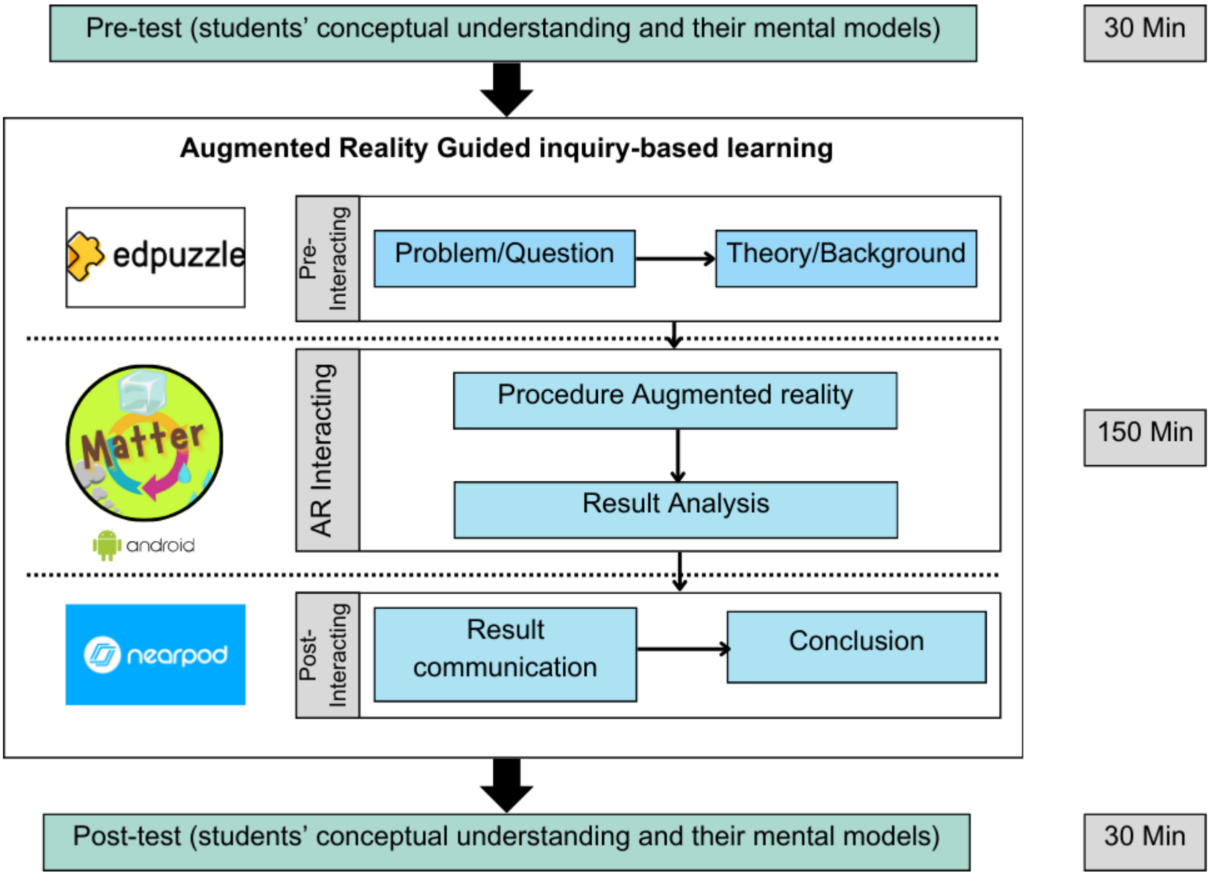

Figure 4. The experimental procedure.

During the Pre-interacting phase, facilitated by Edpuzzle platform, students were introduced to the learning phenomena or question and provided with relevant theoretical background information to establish states of matter for their inquiry. When they finished the learning content, the students had to participate in the background knowledge and assess their prior knowledge via Kahoot. In the AR Interacting phase, students used the augmented reality environment to conduct the main learning activity, the teacher will explain the functions of AR, and how to scan the AR via marker cards in the MATTER app on the tablet. For this process, firstly, teacher divided into 2 types of levels in states of matter, including the observable level and the molecular level. In the first step, students observed ice, water, and steam at the observable level, Then, students began to scan the card to see the arrangement of molecules in solid, liquid, and gas at the molecular level. Moreover, properties in each state of matter occurred by introducing a second card when they collided. This AR showed the animation in each property. They interacted with AR to explore the topic, followed by an analysis of the results they obtained during this exploration.

Finally, in the Post-Interacting phase, supported by Nearpod, students communicated their results and participated in discussions to draw conclusions from their findings. The session completed with a 30-minute post-test aimed to examine the students' conceptual understanding and mental models of solid, liquid, and gas states in order to measure the impact of the augmented reality in a guided inquiry-based learning approach.

4.4 Data Analysis

Before and after to the implementation of an augmented reality in guided inquiry-based learning method, students were administered a conceptual test comprising of eight questions pertaining to the states of matter. The statistical data techniques selected for analyzing students' conceptual understanding were performed by a paired sample t-test in IBM SPSS 28.0 to compare the effect of teaching science in augmented reality integrated guided inquiry-based learning approach. Furthermore, students' mental models, each student was assigned a code of informed, mixed, or naïve to label their drawings. If the drawing were completely and accurate, it would be assigned a code of 'informed'. If the drawing were just partially accurate, it would be assigned a code of 'mixed'. Finally, in the absence of any drawings connected to concepts or the absence of any drawing, it would be assigned a value of naïve.

5. Results

5.1 Students' Conceptual Understanding in States of Matter Concepts

A pre-post test design experiment was conducted with forty-six fourth-grade students in a science classroom to examine the impact of AR in guided inquiry-based learning on the conceptual understanding of states of matter. The students' understanding of concepts was assessed prior to their involvement in the interactive AR in guided inquiry-based learning (pre-test) through a series of five multiple-choice and three open-ended questions. Following that, the students were asked again the same questions to investigate the improvement in their conceptual understanding that resulted from the intervention (the post-test) and to examine their conceptual understanding at the exit.

The post-test conceptual understanding score of students was significantly higher than the pre-test score (t=-15.283, *p*<.05) in this study, as determined by parametric statistics analysis of paired sample t-tests. The statistical result is derived from a paired sample t-test, as illustrated in Table 1.

Table 1*. The Statistical Result is Based on a Paired Sample T-test for Students' Conceptual Understanding in States of Matter*

Conceptual Understanding	N	Mean	S.D.	t	*p*-value
Pretest	46	3.67	2.171	-15.283	.001*
Posttest	46	8.87	1.845		

**p<0.05*

According to the table above, the results indicate that students' post-test scores are significantly higher than their pre-test scores this may be a result of the implementation of AR in guided inquiry-based learning.

5.2 Students' Mental Model in States of Matter Concepts

This study assessed the impact of applying augmented reality in guided inquiry-based learning on primary students' mental model of three concepts of states of matter. The examination of pre-test and post-test answers revealed substantial changes in students' mental model in figure 5.

The analysis of students' mental model of solids shows a percentage shift from a naive conceptualization to a more informed after instruction. Initially, 78.26% of the students had a naive understanding of solids. Only 15.22% of the students demonstrated an informed understanding before learning. However, after intervention, the percentage of students with a percentage accurate understanding increased to 78.26%, while the naive understanding dropped to 13.04%.

For liquids, the pre-learning results revealed that 89.13% of students held a naive understanding, with no students classified as informed. This suggests that liquids were particularly challenging for students to conceptualize. After the instructional intervention, the naive decreased to 15.22%, and the informed increased to 50.00%. However, 34.78% of the students remained in the mixed understanding.

The understanding of gases exhibited the most significant improvement among the three states of matter. Initially, more than half of the students (56.52%) had a naive understanding, and only 15.22% were informed. Post-instruction, the naive category decreased sharply to 4.35%, and the informed understanding soared to 91.30%.

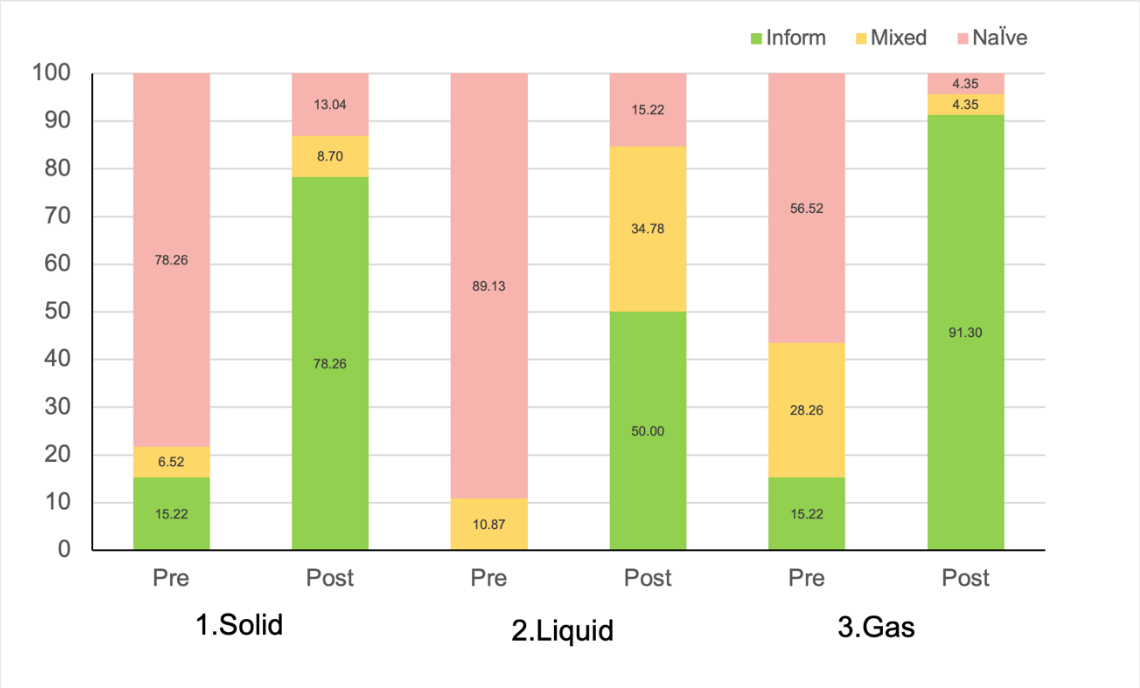

Figure 5. Demonstrated distribution of students’ mental models of states of matter.

6. Discussion and Conclusion

In this study, an augmented reality is proposed for conducting guided inquiry-based learning activities. A learning approach was developed in accordance with the proposed approach and implemented to determine its effectiveness in a primary school science course. The results indicate that the AR technology has the potential to enhance students' understanding of guided inquiry-based learning activity by integrating the observable and molecular levels. Based on the findings of this research, students could enhance their conceptual understanding of the states of matter concept. Regarding the basis of prior research, Chiang, Yang and Hwang (2014) found that the integration of AR with inquiry-based learning significantly enhances students' learning achievements and motivation in natural science activities. Similarly, a mindtool-based AR learning system effectively enhances students' learning achievements in natural science courses, comparable to conventional AR systems, without increasing cognitive load (Wu et al., 2017). In addition, Chen and Liu (2020) indicated that students improved their conceptual understanding of chemistry from the AR learning activity.

Moreover, the percentages seen in students' mental models across all three states of matter (solid, liquid, and gas) indicated that the AR in guided inquiry-based approach effectively promoted students' mental models. Before the intervention, many students displayed naive understandings, particularly for liquids and gases. Following the intervention, the percentage of students who achieved comprehensive knowledge increased, particularly in the case of gases, with 91.30% reaching the informed category. This development emphasizes the impact of augmented reality in supporting students' understanding of the molecular level, namely the arrangement of particles in various states of matter. This is supported by Jeffri and Rambli (2021) highlight the positive impact of AR systems on mental workload and task performance. Similar to Ponners and Piller (2019) shows that augmented reality could effectively deepen elementary students' mental models of both science and scientists, highlighting the potential of AR to influence students' perceptions and understanding of scientific concepts and roles.

In conclusion, the findings indicated that AR in guided inquiry-based learning can be an effective intervention in the field of scientific education, particularly when applied to complicated and abstract concepts such as the states of matter. This approach has the potential to effectively integrate into other science education concepts, fostering science learning in both mental models and conceptual understanding. On the other hand, there is one main limitation in this study that is did not include a control group. Future research could use a comparative study with both an experimental group using AR and a control group applying conventional teaching strategies could provide a clearer basis for assessing the relative efficiency of AR in advancing learning results. Furthermore, investigate the potential for expanding this approach to other educational contexts to explore abstract science concepts such as chemical reactions and their long-term retention.

Acknowledgements

This project is funded by National Research Council of Thailand (NRCT). The authors would like to express gratefully thanks primary school principal and all participants involved in this study. Moreover, ethical approval was obtained from the Human Research Ethics Committee of Khon Kaen University (Ref. HE673390).

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