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Retention and cognitive structures of intermediate primary learners on the concept of phase changes in matter

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Abstract

Scientific concepts such as molecules, elements, and energy transformations are often abstract and inaccessible to learners' direct experiences, making conceptual understanding and retention challenging. This study examined the effectiveness of a States of Matter Physics Education Technology simulation in enhancing grade 6 learners' cognitive structures and retention of phase change concepts. A mixed-method explanatory sequential design was adopted, incorporating pre-test, post-test, delayed post-test, word association tests, and interviews. Sixty-four learners participated, divided into an experimental group taught using the simulation and a control group taught through traditional methods. A validated two-tier diagnostic questionnaire and a Phase Change of Matter Test were administered to measure conceptual understanding and retention. The information processing theory served as the study's theoretical foundation. Results revealed a statistically significant improvement in concept retention among learners exposed to the simulation, indicating its effectiveness over conventional instruction. However, cognitive structure analysis showed persistent reliance on non-scientific terminology. These findings underscore the value of integrating simulations into science instruction and suggest using word association tasks to identify and address learners' misconceptions. The study recommends further research on the long-term effects of such interventions on memory retention.

Keywords*:* Cognitive structure; conceptual retention; instructional simulation; phase change; science education.

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1. INTRODUCTION

Retention of phase change of matter concepts is vital for learners' success in future science and Science, Mathematics, Engineering, and Technology (STEM) related fields (Shemer, 2024). Instructional methods play an important role in learners' retention ability; inappropriate teaching methods in science invariably translate into learners' inability to retain the concepts (Ajayi & Angura, 2017). In South Africa, the learning environment in rural areas is largely teacher-centered, and large classes (Khumalo & Maphalala, 2018). In general, large classes have less than favorable outcomes, including increased reliance on traditional teaching approaches, less active learner engagement, and fewer interactions between teachers and learners. Educators have been encouraged to adopt a variety of teaching strategies both inside and outside of the classroom in order to minimize the unwanted results of teaching large classes and to increase learner long-term retention. One of the promising instructional methods is technology integration, such as simulations, that can enhance the learning and retention of concepts (Shinde & Sarma 2024; Mohafa et al., 2022; Fabeku & Enyeasi 2024).

The use of simulations for science learning is currently widespread (Xodabande et al., 2024; Altun & Serin, 2019; Khlaif et al., 2021; Matute-Vallejo & Melero-Polo, 2019) . In sub-Saharan Africa, the use of simulations is slowly rising, especially in rural primary schools. The simulations are not used interactively but are manipulated by the teachers (Chinaka, 2021; Ndihokubwayo et al., 2020). Recent studies reveal that the use of simulation results in conceptual understanding, retention, increased performance, and learning gains (Woldemariam et al., 2024; Chinaka, 2021; Ndihokubwayo et al., 2020; Sanina et al., 2020). However, there is a dearth of research on retention and cognitive structures related to the use of PhET simulations in science education, especially on the topic of phase change of matter. The term *retention,* as used in the present study, relies on the definition of (Sousa, 2007) (who views retention as a measure of how well a learner remembers the material over time. Sousa (2007) claimed that retention measures how well a learner remembers material over time and is enhanced by instruction methods that support the encoding of information in long-term memory. Retention can be fostered by internal and external factors, such as comprehension of phase change of matter concepts, as well as by external factors such as teaching methods (Engelbrecht et al., 2007).

The cognitive structure is a considerable building block for meaningful learning and retention of instructional materials (Ifenthaler et al., 2011). In addition, it contributes to both the memory of previous knowledge and the acquisition of new information. In assessing subject knowledge as well as prior knowledge, it is useful to determine learners' cognitive structure. The uncovered cognitive structure can provide a topographical map that identifies key learning difficulties and facilitates their resolution (Nakiboğlu, 2023). As a result, educators can develop effective instruction strategies by exposing learners' cognitive structure.

Physics Education Technology Project PhET is a set of interactive, research-based science and mathematics online simulations. Simulations are computer-based representations of natural phenomena that display the outputs of changes in input variables (Correia et al., 2019). A simulation is a software program that allows learners to explore complex interactions among dynamic variables that model real-life situations. Learning natural science and technology is difficult for many learners due to their inability to visualize molecular structures and processes. Correia et al., (2019) recommended to use simulations to build learners' understanding at a sub-microscopic level first to allow them to gradually refine their ideas that can be applied to a larger variety of novel situations in the future.

Scientists have studied matter extensively over the past 30 years, as it is one of the fundamental concepts in science (Özmen, 2013). There have been numerous studies that have examined learners' conceptions of matter, and all levels have difficulties comprehending matter's particulate nature. Learners' understanding of matter as continuous contradicts the particulate nature of matter, which has been attributed to this problem (Savasci-Acikalin, 2021). One of the advantages of simulations is ''the multi-representational visualizations of imperceptible objects and phenomena make explicit the information embedded in external representations with interactive visual displays, thus helping learners perceive the relationship between the representing and represented world" (Taibu et al., 2021). Thus, PhET simulations allow learners to connect to the real world and allow student interaction and inquiry. Simulations are also cost-effective, and they can be useful in schools situated in rural areas. According to Wilcox and Lewandowski (2017), learners from primary schools are more likely to construct new knowledge through multimedia presentations, such as the use of simulations. Few studies have documented the teaching of science in primary schools using states of matter PhET simulations to investigate retention and the cognitive structures**.** In South Africa, learners start to learn about the states of matter (SOM) in Natural Sciences and Technology (NST) from grade 4, where they use physical properties to describe a state of matter. Learners need to understand that matter exists in all phases and that matter can also change its states, by either absorbing or releasing energy. Several studies have explored learners' conceptions of matter and found that learners, at all grade levels, struggle to understand the sub-microscopic nature of matter (Nakhleh et al., 2005; Othman et al., 2008; Singer et al., 2003; Taber & García-Franco, 2010). The researcher explored the use of simulations on learners' conceptual understanding of phase changes of states of matter in grade 6 learners, since such studies have rarely been done in South Africa

This study postulates that grade 6 learners experience difficulties in grasping and understanding many topics and concepts in Natural sciences and technology. One of these topics is states of matter (SOM). The topic is important, and it is the foundation of many sciences, technology, engineering, and mathematics (STEM) disciplines. The SOM is fundamental in NS/Tech and is used to explain the behavior of matter and the complex arrangement of the materials that make up objects. The configuration and behavior of the particles in materials and their interaction with energy at the sub-microscopic level are abstract. The abstract nature of matter and its phase changes are beyond the conceptual understanding of primary and secondary learners if improper instructional approaches are used (Popova & Jones, 2021). This study aimed to investigate the retention and cognitive structures of the SOM PhET simulation among grade 6 learners. The following research questions were set to guide this study:

1. Is there a statistical difference in the retention ability between post-test and delayed post-test mean scores of the grade 6 learners taught with a SOM PhET simulation versus traditional teacher-centered instruction?

2. How does a SOM PhET simulation enhance the retention of phase change of matter concepts among grade 6 learners?

3. What are the cognitive structures of grade six natural sciences learners regarding the topic phase change of matter after instruction?

1.1. Literature review

Physics Education Technology Project PhET is a set of interactive, research-based science and mathematics online simulations. A multimedia software designed as a computer-assisted scaffolding system to teach science and mathematics. The PhET simulations can be used online or offline. Simulations are computer-based representations of natural phenomena that display the outputs of changes in input variables (Correia et al., 2019). A simulation is a software program that allows students to explore complex interactions among dynamic variables that model real-life situations. Learning natural science and technology is difficult for many learners due to their inability to visualize molecular structures and processes. Correia et al., (2019) recommended to use simulations to build learners' understanding at a sub-microscopic level first to allow them to gradually refine their ideas that can be applied to a larger variety of novel situations in the future. One advantage of simulation-based learning is the enhancement of learners' conceptual understanding of scientific phenomena (Quellmalz et al., 2012).

Some studies report improved academic performance when simulations are used to teach and learn stoichiometry concepts in high schools (Ndihokubwayo et al., 2020; Sorden, 2012) . Their studies found that learners exposed to simulations achieved outstanding results in chemical equation balancing and interpretation. These studies were conducted with high school learners, and there is a need to establish the effect of simulations on learners' cognitive structures and retention of phase change of matter concepts under natural science and technology classroom settings in primary schools. In South Africa, available studies on science teaching focused on areas such as the potential of integrating technologies and improving the teaching and learning of natural science and technology. There is a dearth of studies on the actual use and empirical effects of simulations in primary school classrooms, particularly those focusing on the phase change of matter.

Mohafa et al., (2022) Investigated the effect of computer simulations on grade 12 learners' performance and retention of stoichiometry concepts. A quasi-experiment was used to compare the performance between experimental and control groups. The experimental group recorded higher mean scores in the post-test and retention mean scores. Therefore, they concluded that simulations improved learners' performance and retention of stoichiometry concepts. The reported study did not investigate the cognitive structures of the stoichiometry concepts. Thus, the present study sought to investigate how simulations improved retention among primary school learners. Therefore, there is a need to establish the effect of simulations on learners' cognitive structures and retention in natural sciences and technology classroom settings. Mohafa et al., (2022) recommended that simulations be used to supplement the teaching and learning of science, in particular chemistry.

With many science education studies focusing on knowledge retention, retention is treated as one section of a dynamic model of the learning process (Gkitzia et al., 2020). These authors claim that concepts are not immediately or completely forgotten once learned. Moreover, retention decreases over time. Ortiz-Lozano et al., (2020) define the retention interval as a period between the test of the original learning, which proceeds after classroom instruction, and the delayed post-test retention test. Khishfe (2015) differentiates short and long-term retention according to days, weeks, and months. Short-term retention refers to the post-test that is taken after some days and weeks, and long-term retention starts from a month to years. In this study, the delayed post-test was administered after a month, and it fits under long-term retention. Retention over a month was chosen because (Sendur et al., 2017) contend that longer interval retention is harder to assess.

Ajayi and Angura (2017) investigated the students' retention in electrolysis using a collaborative concept mapping instructional strategy (CCMIS). Two instructional methods were compared: CCMIS and discussions. The results of the study revealed that students who were taught using CCMIS had higher statistically significant mean retention scores as compared to those exposed to the other instructional method. Furthermore, the retention ability of the students was not influenced by gender. Thus, it can be concluded that retention is influenced by the instructional approach.

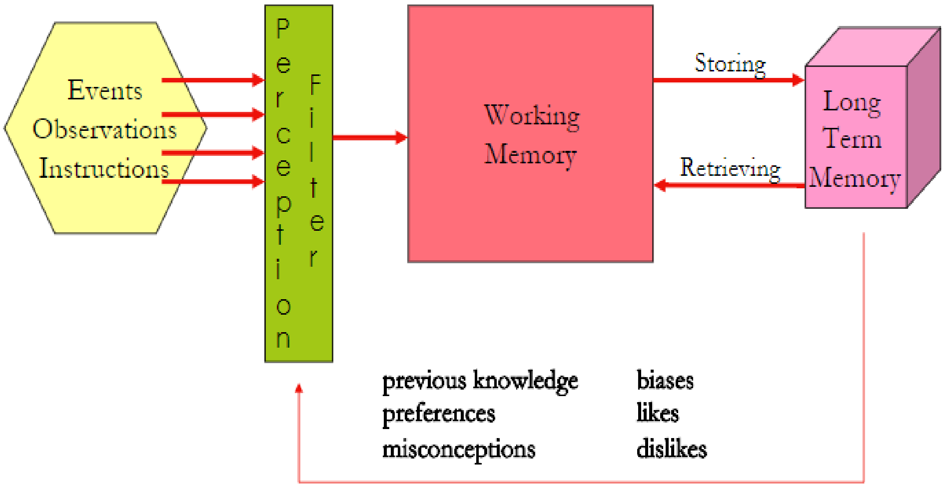
Learners' long-term memory can be modelled in several ways (Nakiboğlu, 2023). Knowledge acquired in science classes is organized hierarchically in long-term memory and can be visualized as a cognitive structure (Miller, 2016). As an integral part of the cognitive structure, learners can reconstruct and process the information they receive as a result of their past experiences and knowledge. Therefore, determining learners' cognitive structure is useful in assessing both subject knowledge and prior knowledge. Exposing learners' cognitive structures can also assist educators in developing appropriate instructional strategies.

1.2. Theoretical framework

Information processing theory is part of the cognitive load theory of learning that entails the processing, retrieval, and retention of knowledge from the brain, as well as storage (Jawad et al., 2021). The theory clarifies how an individual grasps information and can recall it for a long time (Pratiwi et al., 2019). The information acquired is much easier to process if that information is well structured and organized, especially for primary school learners. Schunk (2012) argued that well-structured and organized information can improve memory because the information items are systematically well-connected. According to Schunk, (2012) it is easier to remember the information if it is presented in an organized manner. If the information has been received, it is then encoded and stored in memory. Wickens and Carswell (2021) argued that the storage encompasses how information is sustained over a period, and information is organized in memory. The perception filter (Figure 1) involves the ability of a learner to select important information from the topic phase change of matter. According to (Todd et al., 2012), the perception filter is directly proportional to academic performance. Instructional implications of the perception filter require educators to focus on important points during lessons and avoid irrelevant information. The present study did not follow the full spectrum of the IPM.

Figure 1

Information processing theory adapted



Source: Pratiwi et al., 2019

Information processing begins when an external stimulus is related to one or more of the following: hearing, sight, and touch. Adequate sensory memory takes in external stimuli and stores them in sensory records for a period. Information enters the system via sensory memory but is only stored for a limited period. To stay in the system, information entered into short-term memory is combined with information in long-term memory. Essentially, germane load refers to the capacity of the working memory to link new ideas with long-term memory information.

New information is classified by the brain and stored in long-term memory when a learner is exposed to it. This classification is known as a schema. Schemas are like folders in the memory where information is stored and retained. The weakness of long-term memory is that it is very difficult to access the information stored in it. Learners have difficulty accessing information because accessing information that is tempered is imperfect. However, critics of the CTL and IPM have argued that other factors, such as motivation (Lepper et al., 2005), learners' attitude towards science (phase change of matter), and metacognition (Alexander, 2008)influence learners' educational attainment. In summary, to learn and retain instructional materials effectively, long-term memory is a crucial component. During classroom instruction, information is stored in the short-term memory before being transferred to the long-term memory. Data from the observations of the macroscopic domain is collected through perception filters and processed by comparing with prior experiences in the working memory, and finally meshed into new knowledge and stored in the long-term memory.

1.3. Purpose of study

This study examined the effectiveness of a States of Matter Physics Education Technology simulation in enhancing grade 6 learners' cognitive structures and retention of phase change concepts.

2. METHOD AND MATERIALS

2.1. Research design

The present study used a mixed-method approach within a quasi-experimental descriptive design. The design consists of a sequential quantitative and qualitative phase. The mixed-methods research approach views quantitative and qualitative research designs as complementary (Creswell & Creswell, 2017). The study used a non-equivalent pre-test-post-test, a delayed post-test control group, and interviews in the sequential design. The target population of this study was all grade 6 NS/Tech learners in primary schools of South Africa.

The accessible population was sixty-four grade 6 learners of four public primary schools in the UMkhanyakude district in the KwaZulu-Natal province of South Africa. Four public rural primary schools where the research was conducted were selected mostly for convenience, since the researchers had direct access to the primary schools. Two schools were randomly assigned to experimental and control groups. The experimental groups were taught using a SOM PhET phase simulation, and the control group was taught using a traditional teacher-centered instruction approach. Eight learners were purposively selected for interviews. The time frame for each interview session ranged from 15 to 20 minutes. Due to the global pandemic, COVID-19, all necessary health protocols were observed, such as maintaining social distancing, using face masks throughout the sessions, and sanitizing regularly. Interviews were conducted face-to-face, and all COVID-19 safety measures were observed. The study was conducted for six weeks during the April-June 2022 second term.

2.2. Data collection instrument

The first stage of the instrument development involved defining the content boundaries of the phase change of matter. South Africa's primary school National Curriculum Statement (NCS) for natural sciences and technology was used to define the content scope of the study, encompassing matter & materials, solids, liquids, and gases. The second stage involved reviewing the literature and identifying alternative conceptions that were used as distractors in the first tier of the multiple-choice test. The distractors were based on studies reported by (Adadan et al., 2009; Ayas et al., 2010; Aydeniz & Kotowski, 2012). The phase change of matter test (PCMT) was developed by the researcher to illicit learners' retention of phase changes of matter (Figure 1.2 Question 3). The test consisted of ten two-tier multiple-choice questions. The phase change of matter concepts covered in the PCMT were evaporation, melting, and condensation. Two-tier multiple-choice questions were made up of content-based questions (first tier), Interpretation/justification (second tier) (see figure 1).

Figure 1
Multiple choice question

3.0 You find the inside of the car window getting foggy in winter. This is because of:

A. Condensation

B. Freezing

C. Melting

D. Evaporation

Answer: ....

....

The second instrument was the phase change of matter Word Association Tests (WAT). The WAT represents a tool for exploring aspects of the content and structure of an individual's knowledge in a specific content area (Derman & Eilks, 2016). Four stimulus keywords were provided in a booklet (condensation, freezing, melting, evaporation). Content validity was established by presenting the PMCT and its National curriculum statement (NSC) natural sciences and technology objectives to four teachers to ensure that the content of the test falls within the scope. Teachers were requested to fill out a checklist (yes or no), followed by remarks on each question. The checklist was modelled along (Heale & Twycross, 2015) factors that affect the validity of a measuring instrument: The questions test learners' understanding of phase change of matter, confusing and ambiguous test items are eliminated to ensure that the questions would not be misinterpreted, using vocabulary at the correct level of difficult for test takers, ensuring that each question has only one unequivocal intended response in each tier. Content validity of the WAT was obtained by giving three experienced physical sciences teachers their opinions about the stimulus words used in the study, and it was confirmed that they were suitable for the study. The third instrument was semi-structured interviews. To engage the participant and establish the narrative terrain, interview schedules are developed to guide interviews and provide answers predetermined by the interviewer (Kumar, 2018). By using a semi-structured interview schedule, the researcher could probe for insufficient detail, depth, or clarity in answers. The researcher devised the interview schedule to obtain more detailed information about learners' retention of phase change of matter concepts. A total of four questions based on phase changes of matter were used. Interviews were recorded on a tape recorder, and each interview lasted for 15-20 minutes. In a qualitative study, Kumar (2018) contends that trustworthiness is the degree to which a review merits focusing on, worth observing, together with the degree to which others are persuaded that the discoveries can be relied upon. In the qualitative approach, internal and external validity and reliability are replaced by the criteria of trustworthiness and authenticity. Qualitative research is trustworthy when it accurately represents the experiences of the participants in the study. To ensure trustworthiness, the researchers personally directed interviews where all the participants were recorded accurately, and the recorded data were interpreted fairly. During the treatment stage, the experimental group (EG) was taught with (States of Matter Basics) PhET simulation, and the control group (CG) was the traditional approach, which included teacher explanations, demonstrations, and examples. In the CG, it was a more teacher-centered approach that involved explanations, demonstrations, examples, and illustrations from the teacher in a 'talk-and-chalk' type of lesson. The educators also showed charts, pictures, and PowerPoint figures to the learners.

2.3. Data analysis

The PCMT was administered to all sixty-four grade six natural sciences as a pre-test before the teaching of the phase change of matter. To maintain validity and reliability, the pre-test was written under supervised school examination conditions. The teaching assistants invigilated the pre-test. The learners were not informed about the date of writing the pre-test to avoid studying before the test. The PMCT was written on the same date and time by the experimental and control groups. All the completed and spare PMCT copies were collected by the researcher after the test. The same PCMT was administered after a week as a post-test and after a month as a delayed post-test to test the retention of concepts. The WAT was administered soon after the delayed post-test. Descriptive and inferential statistics were used to analyze quantitative data. Data analysis of the WAT was conducted using the response frequencies' map method proposed. The interview learners' responses were analyzed using a scientifically completed response (nomothetic) and classification of explanations (ideographic). Idiographic and nomothetic methods are two different approaches used to understand social life in the social sciences. A nomothetic method is used to produce "general statements that account for larger social patterns, which form the context of single events, individual behaviors, and experience" (Crossman, 2019). In science education, a nomothetic approach is used to assess definitions of scientifically complete responses by Kabapınar (2009). The study was approved by a letter of approval from the University's Higher Degrees Committee, and an ethical clearance letter was granted from the Faculty Ethics Committee. Any deception of participants, protection of participants from any forms of harm, provision, choice of participation, and confidentiality of data are five important issues related to ethics in research (Mills & Gay, 2016). No one except the researchers had access to the data collected in this study. Learners and parents completed an informed consent form, and the purpose and objective of the study were explained. This study was conducted in public schools, and therefore, all necessary ethical considerations were met.

3. RESULTS

The first research problem focuses on the statistical difference in retention ability between post-test and delayed post-test mean scores of the grade 6 learners taught with a SOM PhET simulation versus traditional teacher-centered instruction. To provide the answer to the first research question, the following null hypothesis was tested: H_0: There is no statistically significant difference in the retention ability of learners taught using the SOM PhET simulation versus those using the teacher-centered method on states of matter concepts. The alternative hypothesis was formulated as follows: H_1: There is a statistically significant difference in the retention ability of learners taught using a SOM PhET simulation versus those taught using the teacher-centered approach on states of matter. The delayed post-test mean scores of the control and experimental groups were subjected to an independent t–test to test the above null hypothesis. The resulting p- p-value was 0.001, implying a statistically significant difference between the two groups' mean scores (Table 1). Thus, the null hypothesis, which stated that there would be no statistically significant difference in retention between the groups, was rejected in favor of its alternative.

Table 1

Delayed-post-test mean scores of the control and experimental groups

Test	Group	N	Mean	Std. Deviation	Std. Error Mean	Df	F	Sig
Delayed post-test	Control	32	53.91	6.558	.595	63	0.523	0.001

Expt	32	60.39	6.369		.558

The mean score obtained in Table 1.0 is 53.91 for the comparison group, which was lower than the mean score for the experimental group (60.39). Thus, the retention ability of the learners taught using the PhET simulation was significantly higher than those taught using the teacher-centered approach. The null hypothesis of no significant difference was therefore rejected in favor of the alternative. This result indicates good retention of states of matter concepts by the experimental group. The results presented in Table 1 show that the PhET simulation improved learners' retention of the phase change of states of matter.

The purposes of the interview were three-fold. Firstly, it was necessary to find out the retention of the learners after treatment with the two interventions, the PhET simulation and the traditional teacher-centered approach. Currently, there is a dearth of educational research in the use of simulations and learners' retention of phase changes of matter in primary schools (Bain & Towns, 2016). Secondly, the researchers sought to find out whether the qualitative data would complement the quantitative data. Kumar (2018) suggested that the use of multiple sources of data is important as it helps to triangulate and ensure the credibility of the research data. Thirdly, semi-structured interviews were conducted to gain insight into the depth and details of learners' retention of the phase change of matter. After the transcription of the recorded data, the responses that learners gave were analyzed using nomothetic and ideographic methods, as suggested by (Küçüközer, 2004). The following key was used: Sound Retention (SR): The response included a correct answer and a scientifically accepted explanation. Partial Retention (PR): Response included at least a correct answer or a scientifically acceptable explanation correct but not both. Incorrect Retention (IR): A response that consisted of an incorrect answer and an illogical explanation.

For learners in the PhET simulation group, their responses were mainly in the SR and PR. Incorrect retention (IRs) from the interview responses were 1 in the PhET group as compared to 5 in the control group. The IRs were like the ones reported from the first phase, which involved quantitative data analysis. In the experimental group, phase changes of water were explained well, and IRs were greatly reduced. Thus, it may be concluded, as was shown from quantitative data, that the use of the PhET simulation greatly improved the retention of phase changes of matter as compared to the control.

3.1. Excerpts from interviews

3.1.1. Interview Questions 1: Explain what causes the changes in the states of water.

One learner from the control group explained that it is caused by adding energy to water. In the experimental group, two learners explained that it is caused by the addition and subtraction of water from the water molecules. The following excerpts are representative of the control and experimental groups on question 1.

Learner D: The common phase change of water is brought about by boiling. If water is heated, it evaporates. Using an electric kettle can bring about a phase change of water from liquid to gas the temperature increases.

Researcher: How about if we put water in the refrigerator?

Learner D: The water will freeze and turn into an ice block. In the fridge, it's cold and the temperature is low.

The learners' response was based on Johnstone's macroscopic level, where phase changes were seen to be affected by temperature. Phase changes require learners to operate at both macroscopic and micro-level. The failure to link the unseen micro-level and qualitative sensory observations may lead to incorrect conceptual understanding.

Leaner H: Phase changes are caused by energy changes that lead to the change of temperature of the water molecules. If energy is taken out of the water molecules, they come close together and form a solid. Freezing forming ice blocks. Taking in and out of the energy causes phase changes.

Researcher: How does the energy enter and out of water?

Leaner H: I saw on the simulation that energy changes from outside the water are the ones responsible for the phase changes. If an ice block is left in the sun, energy will be taken from the sun and change the temperature, which leads to melting.

The response demonstrates a conceptual understanding of both macroscopic and submicroscopic levels. Energy transfer into and out of the system is identified as the driving factor behind phase changes in water. Consequently, the application of the PhET simulation may have contributed to improved retention of concepts related to phase changes of matter. The third question addressed the phenomenon of water freezing.

Learner D: *In the fridge, the temperature is very low, and the water will turn into an ice block. In the fridge low temperatures makes the liquid to go back to the solid phase.*

Researcher: *What happens to the arrangement of the particles as it changes phase*?

Learner D: *The particles will come close together and form a solid*.

Learner F: *Freezing occurs when the energy is taken out of the water molecules, and the particles come together to form a close structure. When energy is taken out, the temperature drops.*

In the two responses, the learner from the experimental group explains that it occurs when energy is taken out of the system, which is the water molecules. There is a distinction between temperature and energy being taken out. The findings show that simulations greatly improved retention through improved visualizations of the particles during phase change.

Table 2 illustrates the frequency of response words associated with the stimulus words. To illustrate the relationship between the stimulus and associated words, a frequency map was created. From Table 2, most learners associated evaporation with an increase in temperature to change phase to gas. Only 17 learners mentioned the arrangement of particles in the gaseous phase. Freezing was mainly associated with coldness, cooling, and energy being taken out. On the other hand, melting was linked to an increase in temperature and hotness. The learners mentioned a decrease in temperature. The frequencies were used to map the cognitive structures after instruction with PhET simulation and traditional teacher-centered approaches.

Table 2

Frequencies of stimulus words WAT

Stimulus words Responses words	Evaporation	Freezing	Melting	Condensation
Cooling		32		12
Energy released/taken		14		17
Energy absorbed/taken in	16		21	
Increase in temperature	38		33	
Decrease in temperature		17		28
hotness	14hot		18	
Free particles	13			
Closely packed		7		
Cold		23		
Loosely packed			13	8

From Table 2 the topographical maps of the cognitive structure are as follows in descending order: Evaporation (Increase in temperature, Energy absorbed, hotness, free particles), Freezing (Cooling, Cold, Decrease in temperature, energy released), Melting (Increase in temperature, Energy taken in, hotness, loosely packed, Condensation (Decrease in temperature, Energy released, Cooling, loosely packed). The cognitive structures show that phase changes are linked to changes in temperature, and very little is known about energy changes that change the arrangement of the particles.

4. DISCUSSION

The first research question was to determine whether or not there would be a statistically significant difference in the retention (post-test and delayed post-test mean scores) of grade 6 learners taught with a SOM PhET simulation versus traditional instruction. The retention ability of the learners taught using the SOM PhET simulation was significantly higher than those taught using the traditional teacher-centered approach. This result indicates good retention of phase change concepts by the experimental group. The delayed post-test performance of the experimental group increased compared to the post-test. The possibility, therefore, exists that the PhET simulation instruction was effective in promoting the learners' retention, resulting in the knowledge being stored in their long-term memories as advocated by the Information processing theory. More specifically, D'Ottonea and Ochonogor (2017) believed that the retention of concepts in chemistry is directly linked to the method of instruction. The findings of this study show that the PhET simulation improved learners' knowledge retention of the phase change of matter.

Furthermore, though the simulation was used as a demonstration by the teachers in the experimental groups instead of the learners' manipulation of the simulation, the delayed post-test mean score was high. The finding concurs with those reported by Ndihokubwayo et al., (2020) who suggested that computer simulations in science education have shown that using simulations interactively or as a demonstration can improve the effectiveness of instruction. Also, in general, having the learners manipulate the simulation themselves or as a demonstration yields the same overall outcomes (Ndihokubwayo et al., 2020). The findings seem to suggest that the PhET simulation has the potential to improve learners' retention of targeted chemical phenomena, such as the phase change of matter. The finding also suggests that retention is one of the best predictors of academic success in science education (Schwedler & Kaldewey, 2020). The present study concurs with (Mohafa et al., 2022) who recommended that simulations be used to supplement the teaching and learning of science, to enhance performance and retention.

The findings on the use of the PhET simulation were similar to those by Didiş (2015), which shows that learners enjoyed the simulation, and it improved the conceptual understanding and retention of quantum theory concepts. The traditional approach had the least retention, and it is concluded that the use of the PhET simulation leads to better retention of phase change of matter concepts. The findings of this study on the traditional approach are in agreement with several related research studies

(D'Ottonea & Ochonogor, 2017; Shahani & Jenkinson, 2016; Taylor et al., 2017) that concluded teaching approaches have a direct effect on retention. According to the information processing theory, the use of the PhET simulation might have allowed new knowledge to be created when the prior knowledge interacted with information from the simulation in the long-term memory. The results are in agreement with Savasci-Acikalin (2019) who suggested that simulations have the potential to improve the visualization of abstract concepts. The findings seem to suggest that improved visualization tends to improve the retention of concepts.

We can say that learners' cognitive structures related to phase change of matter, in the case of this study, showed that most learners rely on temperature increases and decreases in temperature to explain phase change of matter. The topography of the cognitive structures shows that learners lacked scientific terminology and often used hotness and coldness. The current findings overlap with other studies in chemistry (Adams, 2012; Calik & Ayas, 2005; Nakiboğlu, 2023) but this study provides a further, deeper view into learners' retention of the phase change of matter. The findings have shown that learners' cognitive structure networks often remain weak and non-interactive. This finding reveals that learners' cognitive structures may be altered when visualizations of abstract concepts are improved.

5. CONCLUSION

In this study, we explored grade 6 Natural Sciences and Technology learners' retention and cognitive structures after instruction. We found that learners' retention was greatly influenced by the instructional approach. Thus, the retention ability of the learners taught using the SOM PhET simulation was significantly higher than those taught using the traditional teacher-centered approach. We also found that the cognitive structure after the WAT test was dominated by words such as hotness and coldness when the matter changed phase. The topography of the cognitive lacked proper scientific terminology that clearly distinguished heat and temperature. Furthermore, few learners linked phase change to energy changes and the particle model of matter. We also conclude that teachers should develop intimate knowledge of their learners' cognitive structures as part of their pedagogical content knowledge before teaching the phase change of matter. By tailoring the teaching process, teachers will help learners acquire knowledge based on scientific evidence.

To design instruction that meets the needs of their learners, NSC/ Tech teachers can apply the WAT to determine their existing knowledge, misconceptions, and cognitive structures. Considering the findings discussed above, we can conclude that natural science curriculum developers, textbook writers, and teachers must continue to implement carefully designed teaching materials and activities to enhance learner retention and reliable cognitive structures. The findings of this study concur with the IPT that knowledge acquired by learners in natural sciences and technology classes is stored in their long-term memory in a hierarchically organized form and can be represented as a cognitive structure in their memory. The cognitive structure is a combination of the learners' existing experiences and knowledge acquired during classroom activities that lead to their reconstruction.

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REFERENCES

Adadan, E., Irving, K. E., & Trundle, K. C. (2009). Impacts of multi-representational instruction on high school students' conceptual understandings of the particulate nature of matter. *International journal of science education*, *31*(13), 1743-1775. https://www.tandfonline.com/doi/abs/10.1080/09500690802178628

Adams, K. (2012). *Beginning chemistry teachers' use of the triplet relationship during their first three years in the classroom*. Arizona State University. https://search.proquest.com/openview/6e4609ce9761824160cc4f520fe5b637/1?pq-origsite=gscholar&cbl=18750

Ajayi, V. O., & Angura, T. (2017). Improving Senior Secondary Students' Retention in Electrolysis Using Collaborative Concept Mapping Instructional Strategy (CCMIS). *Greener Journal of Educational Research*, *7*(6), 87-92. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3032913

Alexander, P. A. (2008). Why this and why now? Introduction to the special issue on metacognition, self-regulation, and self-regulated learning. *Educational Psychology Review*, *20*, 369-372. https://link.springer.com/article/10.1007/s10648-008-9089-0

Altun, H., & Serin, O. (2019). Determination of Learning Styles and Achievements of Talented Students in the Fields of Science and Mathematics. *Cypriot Journal of Educational Sciences*, *14*(1), 80-89. https://eric.ed.gov/?id=EJ1211722

Ayas, A., Özmen, H., & Çalik, M. (2010). STUDENTS' CONCEPTIONS OF THE PARTICULATE NATURE OF MATTER AT SECONDARY AND TERTIARY LEVEL. *International journal of science and mathematics education*, *8*, 165-184. https://link.springer.com/article/10.1007/s10763-009-9167-x

Aydeniz, M., & Kotowski, E. L. (2012). What do middle and high school students know about the particulate nature of matter after instruction? Implications for practice. *School Science and Mathematics*, *112*(2), 59-65. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1949-8594.2011.00120.x

Chinaka, T. W., Sondlo, A. & Nkosi, L. (2025). Retention and cognitive structures of intermediate primary learners on the concept of phase changes in matter. *Contemporary Educational Research Journal*, *15*(2), 108-123. https://doi.org/10.18844/cerj.v15i2.9701

Bain, K., & Towns, M. H. (2016). A review of research on the teaching and learning of chemical kinetics. *Chemistry Education Research and Practice*, *17*(2), 246-262. https://pubs.rsc.org/en/content/articlehtml/2016/rp/c5rp00176e

Calik, M., & Ayas, A. (2005). A comparison of the level of understanding of eighth-grade students and science student teachers related to selected chemistry concepts. *Journal of research in science teaching*, *42*(6), 638-667. https://onlinelibrary.wiley.com/doi/abs/10.1002/tea.20076

Chinaka, T. W. (2021). The effect of PhET simulation vs. phenomenon-based experiential learning on students' integration of motion along two independent axes in projectile motion. *African Journal of Research in Mathematics, Science and Technology Education*, *25*(2), 185-196. https://www.tandfonline.com/doi/abs/10.1080/18117295.2021.1969739

Correia, A. P., Koehler, N., Thompson, A., & Phye, G. (2019). The application of PhET simulation to teach gas behavior on the submicroscopic level: secondary school students' perceptions. *Research in Science & Technological Education*, *37*(2), 193-217. https://www.tandfonline.com/doi/abs/10.1080/02635143.2018.1487834

Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.

Crossman, A. (2019). Definition of idiographic and nomothetic. *ThoughtCo, Oct 25*, 2019.

D'Ottone, L., & Ochonogor, E. C. (2017). Educational explorations of chemical kinetics in a Problem-Based Learning context. *Orbital: The Electronic Journal of Chemistry*, 299-307. https://desafioonline.ufms.br/index.php/orbital/article/view/16456

Derman, A., & Eilks, I. (2016). Using a word association test for the assessment of high school students' cognitive structures on dissolution. *Chemistry Education Research and Practice*, *17*(4), 902-913. https://pubs.rsc.org/en/content/articlehtml/2016/rp/c6rp00084c

Didiş, N. (2015). The analysis of analogy use in the teaching of introductory quantum theory. *Chemistry Education Research and Practice*, *16*(2), 355-376. https://pubs.rsc.org/en/content/articlehtml/2015/rp/c5rp00011d

Engelbrecht, J., Harding, A., & Du Preez, J. (2007). Long-term retention of basic mathematical knowledge and skills with engineering students. *European Journal of Engineering Education*, *32*(6), 735-744. https://www.tandfonline.com/doi/abs/10.1080/03043790701520792

Fabeku, O. E., & Enyeasi, S. C. (2024). Computer simulation and video media instructional packages in improving learning outcomes of Chemistry students in Ife Central Local Government Area. *Disciplinary and Interdisciplinary Science Education Research*, *6*(1), 19. https://link.springer.com/article/10.1186/s43031-024-00109-5

Gkitzia, V., Salta, K., & Tzougraki, C. (2020). Students' competence in translating between different types of chemical representations. *Chemistry Education Research and Practice*, *21*(1), 307-330. https://pubs.rsc.org/en/content/articlehtml/2019/rp/c8rp00301g

Heale, R., & Twycross, A. (2015). Validity and reliability in quantitative studies. *Evidence-based nursing*, *18*(3), 66-67. https://ebn.bmj.com/content/18/3/66.short

Ifenthaler, D., Masduki, I., & Seel, N. M. (2011). The mystery of cognitive structure and how we can detect it: tracking the development of cognitive structures over time. *Instructional Science*, *39*, 41-61. https://link.springer.com/article/10.1007/s11251-009-9097-6

Jawad, L. F., Raheem, M. K., & Majeed, B. H. (2021). The Effectiveness of Educational Pillars Based on Vygotsky's Theory in Achievement and Information Processing Among First-Intermediate Class Students. *International Journal of Emerging Technologies in Learning (iJET)*, *16*(12), 246-262. https://www.learntechlib.org/p/220058/article_220058.pdf

Kabapınar, F. M. (2009). Multi-frame illustrations: A molecular visual strategy in learning and teaching chemistry concepts. *Australian Journal of Education in Chemistry*, *69*, 11-16.

Khishfe, R. (2015). A look into students' retention of acquired nature of science understandings. *International Journal of Science Education*, *37*(10), 1639-1667. https://www.tandfonline.com/doi/abs/10.1080/09500693.2015.1049241

Khlaif, Z. N., Salha, S., & Kouraichi, B. (2021). Emergency remote learning during COVID-19 crisis: Students' engagement. *Education and information technologies*, *26*(6), 7033-7055. https://link.springer.com/article/10.1007/S10639-021-10566-4

Khumalo, N. P., & Maphalala, M. C. (2018). Students' perspectives on the role played by academic literacy in the higher education curriculum of South Africa. *Journal of Gender, Information and Development in Africa (JGIDA)*, *7*(1), 155-173. https://journals.co.za/doi/abs/10.10520/EJC-eea0e5573

Küçüközer, H. (2004). The influence of the teaching method which was designed according to constructivist learning theory for the first year high school students' on simple electric circuit. *Unpublished Ph. D. Thesis, Balıkesir University, Balıkesir, Turkey*.

Kumar, R. (2018). Research methodology: A step-by-step guide for beginners. https://www.torrossa.com/gs/resourceProxy?an=5018508&publisher=FZ7200

Lepper, M. R., Corpus, J. H., & Iyengar, S. S. (2005). Intrinsic and extrinsic motivational orientations in the classroom: Age differences and academic correlates. *Journal of educational psychology*, *97*(2), 184. https://psycnet.apa.org/fulltext/2005-05100-004.html

Matute-Vallejo, J., & Melero-Polo, I. (2019). Understanding online business simulation games: The role of flow experience, perceived enjoyment and personal innovativeness. *Australasian Journal of Educational Technology*, *35*(3). https://ajet.org.au/index.php/AJET/article/view/3862

Miller, L. M. (2016). *Response to intervention: a mixed-methods longitudinal study of the differences in reading achievement within a school district*. Ball State University. https://search.proquest.com/openview/446f52e1afb3f7e49cca7baf1943b450/1?pq-origsite=gscholar&cbl=18750

Mills, G. E., & Gay, L. R. (2016). *Educational research: Competencies for analysis and applications*. pearson.

Mohafa, L. G., Qhobela, M., & George, M. J. (2022). Evaluating the influence of interactive simulations on learners' academic performance in stoichiometry. *South African Journal of Chemistry*, *76*, 01-08. https://www.ajol.info/index.php/sajc/article/view/241072

Nakhleh, M. B., Samarapungavan, A., & Saglam, Y. (2005). Middle school students' beliefs about matter. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *42*(5), 581-612. https://onlinelibrary.wiley.com/doi/abs/10.1002/tea.20065

Nakiboglu, C. (2008). Using word associations for assessing non major science students' knowledge structure before and after general chemistry instruction: the case of atomic structure. *Chemistry Education Research and Practice*, *9*(4), 309-322. https://pubs.rsc.org/en/content/articlehtml/2008/rp/b818466f

Nakiboğlu, C. (2023). Investigation of students' cognitive structures concerning the topic of physical and chemical changes: a cross-level study. *Chemistry Education Research and Practice*, *24*(1), 89-107. https://pubs.rsc.org/en/content/articlehtml/2022/rp/d2rp00142j

Ndihokubwayo, K., Uwamahoro, J., & Ndayambaje, I. (2020). Effectiveness of PhET simulations and YouTube videos to improve the learning of optics in Rwandan secondary schools. *African Journal of Research in Mathematics, Science and Technology Education*, *24*(2), 253-265. https://journals.co.za/doi/abs/10.1080/18117295.2020.1818042

Ortiz-Lozano, J. M., Rua-Vieites, A., Bilbao-Calabuig, P., & Casadesús-Fa, M. (2020). University student retention: Best time and data to identify undergraduate students at risk of dropout. *Innovations in education and teaching international*. https://www.tandfonline.com/doi/shareview/10.1080/14703297.2018.1502090

Othman, J., Treagust, D. F., & Chandrasegaran, A. L. (2008). An investigation into the relationship between students' conceptions of the particulate nature of matter and their understanding of chemical bonding. *International Journal of Science Education*, *30*(11), 1531-1550. https://www.tandfonline.com/doi/abs/10.1080/09500690701459897

Özmen, H. (2013). A cross-national review of the studies on the particulate nature of matter and related concepts. *International Journal of Physics & Chemistry Education*, *5*(2), 81-110. https://ijpce.org/index.php/IJPCE/article/download/77/87

Chinaka, T. W., Sondlo, A. & Nkosi, L. (2025). Retention and cognitive structures of intermediate primary learners on the concept of phase changes in matter. *Contemporary Educational Research Journal*, *15*(2), 108-123. https://doi.org/10.18844/cerj.v15i2.9701

Popova, M., & Jones, T. (2021). Chemistry instructors' intentions toward developing, teaching, and assessing student representational competence skills. *Chemistry Education Research and Practice*, *22*(3), 733-748. https://pubs.rsc.org/en/content/articlehtml/2021/rp/d0rp00329h

Pratiwi, E., Nusantara, T., Susiswo, S., Muksar, M., & Subanji, S. (2019). Characteristics of students' cognitive conflict in solving a problem based on information processing theory. *International Journal of Learning, Teaching and Educational Research*, *18*(2), 76-88. http://www.ijlter.myres.net/index.php/ijlter/article/view/596

Quellmalz, E. S., Timms, M. J., Silberglitt, M. D., & Buckley, B. C. (2012). Science assessments for all: Integrating science simulations into balanced state science assessment systems. *Journal of Research in Science Teaching*, *49*(3), 363-393. https://onlinelibrary.wiley.com/doi/abs/10.1002/tea.21005

Sanina, A., Kutergina, E., & Balashov, A. (2020). The Co-Creative approach to digital simulation games in social science education. *Computers & education*, *149*, 103813. https://www.sciencedirect.com/science/article/pii/S0360131520300154

Savasci-Acikalin, F. (2021). How middle school students represent phase change and interpret textbook representations: A comparison of student and textbook representations. *Research in Science Education*, *51*, 1651-1685. https://link.springer.com/article/10.1007/s11165-019-9834-z

Schunk, D. H. (2012). *Learning theories: an educational perspective,* sixth edition: Pearson.

Schwedler, S., & Kaldewey, M. (2020). Linking the submicroscopic and symbolic level in physical chemistry: how voluntary simulation-based learning activities foster first-year university students' conceptual understanding. *Chemistry Education Research and Practice*, *21*(4), 1132-1147. https://pubs.rsc.org/en/content/articlehtml/2020/rp/c9rp00211a

Sendur, G. Ü. L. T. E. N., Polat, M., & Kazancı, C. (2017). Does a course on the history and philosophy of chemistry have any effect on prospective chemistry teachers' perceptions? The case of chemistry and the chemist. *Chemistry Education Research and Practice*, *18*(4), 601-629. https://pubs.rsc.org/en/content/articlehtml/2017/rp/c7rp00054e

Shahani, V. M., & Jenkinson, J. (2016). The efficacy of interactive analogical models in the instruction of bond energy curves in undergraduate chemistry. *Chemistry Education Research and Practice*, *17*(2), 417-428. https://pubs.rsc.org/en/content/articlehtml/2016/rp/c5rp00194c

Shemer, G. (2024). Playing it SMART: increasing transfer student and URM undergraduate student success through undergraduate research combined with group support. In *Frontiers in Education, 9*, 1465803. https://www.frontiersin.org/journals/education/articles/10.3389/feduc.2024.1465803/full

Shinde, N., & Sarma, H. (2024). Enhancing STEM curriculum with virtual reality: electricity and magnetism simulations. *Multimedia Tools and Applications*, 1-20. https://link.springer.com/article/10.1007/s11042-024-20387-5

Singer, J. E., Tal, R., & Wu, H. K. (2003). Students' understanding of the particulate nature of matter. *School Science and Mathematics*, *103*(1), 28-44. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1949-8594.2003.tb18111.x

Sorden, S. D. (2012). The cognitive theory of multimedia learning. *Handbook of educational theories*, *1*(2012), 1-22.

Sousa, D. A. (Ed.). (2007). *How the brain learns mathematics*. Corwin Press. https://books.google.com/books?hl=en&lr=&id=Bc8hAQAAQBAJ&oi=fnd&pg=PR9&dq=Sousa,+D.+A.+(2008).+Facilitator%27s+Guide,+How+the+Brain+Learns+Mathematics.+Corwin+Press.+&ots=Gfzlz76o9u&sig=3CpulJXNafQEEhcTf_sH6CcLx1o

Taber, K. S., & García-Franco, A. (2010). Learning processes in chemistry: Drawing upon cognitive resources to learn about the particulate structure of matter. *The Journal of the Learning Sciences*, *19*(1), 99-142. https://www.tandfonline.com/doi/abs/10.1080/10508400903452868

Taibu, R., Mataka, L., & Shekoyan, V. (2021). Using PhET simulations to improve scientific skills and attitudes of community college students. https://academicworks.cuny.edu/qb_pubs/81/

Taylor, A. T., Olofson, E. L., & Novak, W. R. (2017). Enhancing student retention of prerequisite knowledge through pre-class activities and in-class reinforcement. *Biochemistry and Molecular Biology Education*, *45*(2), 97-104. https://iubmb.onlinelibrary.wiley.com/doi/abs/10.1002/bmb.20992

Todd, R. M., Cunningham, W. A., Anderson, A. K., & Thompson, E. (2012). Affect-biased attention as emotion regulation. *Trends in cognitive sciences*, *16*(7), 365-372. https://www.cell.com/trends/cognitive-sciences/fulltext/S1364-6613(12)00129-5?large_figure=true

Wickens, C. D., & Carswell, C. M. (2021). Information processing. *Handbook of human factors and ergonomics*, 114-158. https://onlinelibrary.wiley.com/doi/abs/10.1002/9781119636113.ch5

Wilcox, B. R., & Lewandowski, H. J. (2017). Developing skills versus reinforcing concepts in physics labs: Insight from a survey of students' beliefs about experimental physics. *Physical Review Physics Education Research*, *13*(1), 010108. https://journals.aps.org/prper/abstract/10.1103/PhysRevPhysEducRes.13.010108

Woldemariam, D. Y., Ayele, H. S., Kedanemariam, D. A., Mengistie, S. M., & Beyene, B. B. (2024). Effects of technology-assisted chemistry instruction on students' achievement, attitude, and retention capacity: A systematic review. *Education and Information Technologies*, *29*(11), 13763-13785. https://link.springer.com/article/10.1007/s10639-023-12411-2

Xodabande, I., Atai, M. R., & Hashemi, M. R. (2024). Exploring the effectiveness of mobile assisted learning with digital flashcards in enhancing long-term retention of technical vocabulary among university students. *Journal of Computers in Education*, 1-26. https://link.springer.com/article/10.1007/s40692-024-00347-6