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Effect of physics education technology project simulation on improvement of retention ability of grade six learners in state of matter

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Abstract: Physics Education Technology Project (PhET) simulation gives students the opportunity to explore and experiment with scientific phenomena in a safe, virtual setting. This study investigated the effects of PhET improvement on the retention ability of grade six learners in state of matter (SOM). To achieve the aim of the study sixty-four grade six learners were considered from four randomly selected primary schools in Umkhanyakude District in KwaZulu-Natal province. The study utilized a quasi-experimental design with a non-equivalent pre-test, post-test, and delayed post-test approach. Data were collected using the Phase Change of Matter Test (PCMT) administered during the pre-test, post-test, and delayed post-test phases. Participants in the control group were taught using the traditional teacher-centered approach, while the experimental group was exposed to the SOM PhET simulation. The reliability coefficient of 0.75 was determined using Cronbach's alpha reliability coefficient. The data were analyzed using descriptive statistics, including mean, median, standard deviation, and range, to summarize the pre-test, post-test, and delayed post-test scores for both groups. A paired samples t-test was also conducted for each group to compare the pre-test and post-test scores, as well as the post-test and delayed post-test scores, to assess whether there was a significant improvement in retention following the intervention. The findings indicated that using PhET as an intervention effectively enhanced conceptual understanding of SOM. There was a statistically significant difference in the retention ability after treatment with a PhET simulation, compared to the control group. Based on the findings, it is recommended that students actively interact with simulations rather than merely observing demonstrations. When students engage directly with these tools, they achieve a deeper understanding and improved learning outcomes.

Keywords: *Instructional method, Learner academic performance, Physics education technology project, Science education, State of matter.*

1. Introduction

The rise of computer tools, such as the Physics Education Technology (PhET) Project Simulation, seeks to transform and improve the teaching and learning of physics. This is because the quality of science teaching and mastery at the primary school level is crucial for learner success and development. However, many primary school learners in South Africa are facing challenges in grasping and understanding concepts in Natural Sciences and Technology (Siphukhanyo & Olawale, 2024; Mabangula, 2023). One of these concepts is states of matter (SOM). The topic is important, and it is the foundation of many Sciences, Technology, Engineering and Mathematics (STEM) disciplines (Council, 2012). The SOM is fundamental in Natural Science and Technology (NS/Tech) and is used to explain the behaviour of matter and the complex arrangement of the materials that make up objects. The configuration and behaviour 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

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conceptual understanding of primary and secondary learners if improper instructional approaches are used (Popova & Jones, 2021).

Several studies (Aydeniz & Kotowski, 2012; Badrian et al., 2011; Hejnová & Králík, 2019) have found that learners from primary school to university have difficulty understanding the particle nature of matter which is central to understanding the SOM. Hejnová and Králík (2019) suggested that the particle nature of the matter concept is abstract and difficult to visualise. There are other learning obstacles to the concept, including the simple representations and analogies in lessons and books based on the historical process, and the inability to specify motion positions in these expressions (Türkoguz & Ercan, 2022). According to (Talanquer, 2018), learners' conceptual understanding in SOM requires versatility among macroscopic and microscopic, and their symbolic representations. The traditional instructional approach of SOM involves the use of charts, chalkboards and textbooks (Özmen, 2013a).

The 'chalk and talk' teacher-centred approach is the prevalent instruction in most rural primary schools (Mpuangnan et al., 2024). A research study acknowledged that schools situated in rural areas in South Africa lack the proper study materials that enhance learning (Dube et al., 2024). Most teachers in these places rely mostly on textbooks (Khumalo and Maphalala, 2018). Textbooks are one of the teaching tools frequently used in schools. In addition, textbooks are also a major source of representation that learners encounter in science classes. Popova and Jones (2021) discussed that textbooks do not provide the dynamic nature of particles when matter changes phase.

There is great consensus among researchers that high-quality Science education teaching and learning at the primary school level is fundamental for learner success (Popova & Bretz, 2018; Popova et al., 2020). Many countries have adopted the use of simulations in science education among primary learners as fundamental to enhancing success in STEM (Buthelezi & Mpuangnan, 2024). Despite various countries focussing on primary school Science education, such attention has not been evident in South Africa (Set et al. (2017), especially in NS/Tech (grades 4–6). There has been a paucity of research related to the SOM and conceptual understanding of phase change of matter related to the South African context. In the present study, the researcher sought to investigate the Grade 6 NS/Tech learners' conceptual understanding of the topic SOM.

Set et al. (2017) contended that NS/Tech teaching hardly supports conceptual understanding. The researcher believes that active learning, involving learners' Physics Education Technology Project (PhET) simulations, rather than relying on traditional instructional approaches, would enhance their conceptual understanding of abstract and complex concepts of SOM. Knowledge retention is mostly influenced by classroom activities as well as memory (Khasawneh et al., 2024). The reliance of learners on rote skills risks NS/Tech becoming just a mnemonic exercise. Educators should strive to teach for conceptual understanding that may lead to better retention. The use of simulations is expected to promote learner engagement and improve conceptual understanding and retention of states of matter concepts among primary school learners.

Learners of all ages often struggle with understanding the particle nature of matter and may find it challenging to explain the dynamic behaviour of particles at a microscopic level, particularly during phase changes. Because phase changes involve invisible processes, they require a detailed microscopic explanation. This difficulty can be exacerbated by inadequate teaching methods and insufficient explanations using scientific terminology, leading to gaps in conceptual understanding and retention. Popova and Bretz (2018) suggest that using multiple representations such as modelling, simulations, and animations can effectively bridge the gap between macroscopic and microscopic perspectives. Integrating emerging technologies into instruction is a hopeful strategy for cultivating students' learning and retention of scientific concepts.

1.1. Research Question

Is there a statistically significant difference in the learning outcomes of students taught using PhET simulations versus those taught using traditional instructional methods?

1.2. Hypothesis

H_0: There is no statistically significant difference between the pre-test and post-test mean scores of the learners taught using the PhET simulation approach and those taught using a traditional teacher-centred instructional approach.

H_1: There is a statistically significant difference between the pre-test and post-test mean scores of the students taught using the PhET approach and those taught using a traditional lecture-centred instructional approach.

2. Literature Review

Physics Education Technology (PhET) simulations is used for teaching and learning of scientific concepts (Wilcox & Lewandowski, 2017). Another PhET simulation is computer simulations. According to Winsberg (2013), the term computer simulation is used in both a narrow and a broad sense. Some may want to grasp the term from more than one sentiment. Parker (2013) describes computer simulations as an inventive way to transfer scientific ideas and unite learners in educational activities. Research has shown that interactive simulations can greatly boost the effectiveness of teaching in chemistry (Taibu et al., 2021). These simulations can help make complex chemical concepts clearer for students and enhance their understanding and engagement.

It is widely acknowledged that high-quality science teaching and strong foundational knowledge at the primary school level are vital for students' future success and development (Halverson, 2007). The concept of the particulate nature of matter (PNM) has gained significance with the advancement of Natural Science and Technology (NS/Tech). At its core, PNM is based on the concept of atoms and atomic models, and it is fundamental to understanding key ideas in both chemistry and physics. PNM is essential for grasping everyday concepts such as the structure and states of matter, osmosis, diffusion, solutions, solubility, and chemical reactions (Türkoguz, 2020). Research consistently indicates that students from primary to tertiary education levels struggle to understand the concept of PNM (Adadan et al., 2009; Aydeniz et al., 2017; Stojanovska et al., 2012). NS/Tech encompasses topics that can be challenging for students, such as the phase change of matter, which requires visualization and abstract thinking and is often taught using language that differs from everyday use (Hejnová & Králík, 2019).

The Department of Basic Education in South Africa introduced the Curriculum and Assessment Policy Assessment Statement (CAPS) in 2012, which was designed to motivate the engagement of learners in gaining knowledge conceptually across different grades and learning areas (Moodley, 2013). However, in rural schools of KwaZulu-Natal (KZN), instructional approaches remain largely teacher-centred. Most teachers working in public primary schools use chalkboards and charts to teach about the phase changes of matter. Fitzgerald and Smith (2016) posited that most South African teachers, especially in primary schools, depend only on textbooks. It is also difficult to grasp the concept because the PNM is presented in classrooms and books in simple representations and analogies based on the historical process, and motion positions cannot be given in these expressions (Yaseen & Akaygun, 2016). Conceptual understanding of NS/Tech in primary schools also depends on three levels of representation, namely macroscopic, symbolic, and sub-microscopic (Nyachwaya & Gillaspie, 2016). The macroscopic refers to the visible and tangible; symbolic refers to mathematical interpretations and formulas; and the sub-microscopic represents atoms, molecules, ions and structures (Gilbert & Treagust, 2009). Learners live in the macroscopic world, and they must create their own representation to gain some understanding of the dynamic nature of particles at a sub-microscopic level. The dynamic motion of particles at the sub-microscopic level, resulting in energy changes and phase changes, is abstract and cannot be explained using books and charts.

Learners come to school having abundant first-hand experience with the change of state. The reciprocal processes of evaporation and condensation have been central to many studies on learners' conceptual understanding (Smith, 2016). Aydeniz and Kotowski (2012) reported that grade five students attributed the condensation on a glass of cold water to seepage of water through the glass. Furthermore, some thought that the cold surface reacted with the dry air to form water by allowing oxygen and hydrogen to react. In a similar study, Durmuş and Bayraktar (2010) reported that some learners thought that evaporation occurs only at very high temperatures, whereas others believed that evaporation occurs only when liquids boil. Savasci-Acikalin (2019) reported grade 6 learners' conceptual understanding of phase change of matter using textbook representations. The learners' representations of phase change did not match the scientific notions. Furthermore, the textbook representations did not help learners to understand the particle dynamics at the sub-microscopic level during phase changes. One of the recommendations was to provide more guidance, and discussions and change instructional approaches.

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. It is essential for students 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 Yaseen and Akaygun (2016) 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.

Research highlights those interactive simulations can make a big difference in science education (Yaseen & Akaygun, 2016). These simulations offer a simplified view of the natural world, helping students grasp complex chemical concepts more clearly. Physics Education Technology (PhET) simulations have been especially effective in helping students understand abstract scientific ideas (Inayah & Masruroh, 2021).

One of the advantages of simulations is that "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. There are a few studies that have documented the teaching of science in primary schools; more studies focus on the secondary school level, especially grade 12 (Bantwini, 2017). The researcher, therefore, intends to explore the effectiveness of the use of the states of matter PhET simulations on grade 6 learners of selected primary schools of uMkhanyakude district, in KwaZulu-Natal, South Africa.

In a study involving the effect of using a Virtual Laboratory on Grade 10 learners' conceptual understanding and their attitudes towards science Abou Faour and Ayoubi (2017) found that most learners relied on rote skills and lacked a recall of important concepts learnt the previous term. Knowledge retention is mainly influenced by memory and classroom activities. Science as a discipline risk being a mnemonic exercise if learners fail to retain core knowledge concepts that drive phase changes. The retention of core knowledge concepts by learners may be a research niche in science education that has the potential to inform instructional practices in primary schools.

According to Lysne and Miller (2017) retention as the ability of a learner to remember what has been learned over time and it is influenced by instructional approaches. Furthermore, retention is the extent to which learners can successfully retrieve core knowledge concepts from long-term memory. Instructional methods play an important role in the retention ability of learners. Inappropriate instructional approaches in science invariably translate to learners' inability to retain core knowledge concepts (Ajayi & Angura, 2017). In South Africa, NS/Tech lessons are usually large classes. The traditional teacher centred approach is the modus operandi. The researcher considered the idea of a PhET simulation, which involve the active participation of the students, would improve the retention of phase change concepts.

3. Theoretical Framework

Information processing theory (IPT) was used to underpin this study. IPS 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). This theory clarify how an individual grasp 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 (Mayer, 2012)argued that well-structured and organized information can improve memory because the information items are systematically well connected to one another. According to Clewett et al. (2019) it is easier to remember the information if it presented in an organised manner. If the information has been received, it is then encoded and stored in memory. Norris (2017) 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 Klahr and Wallace (2022), 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.

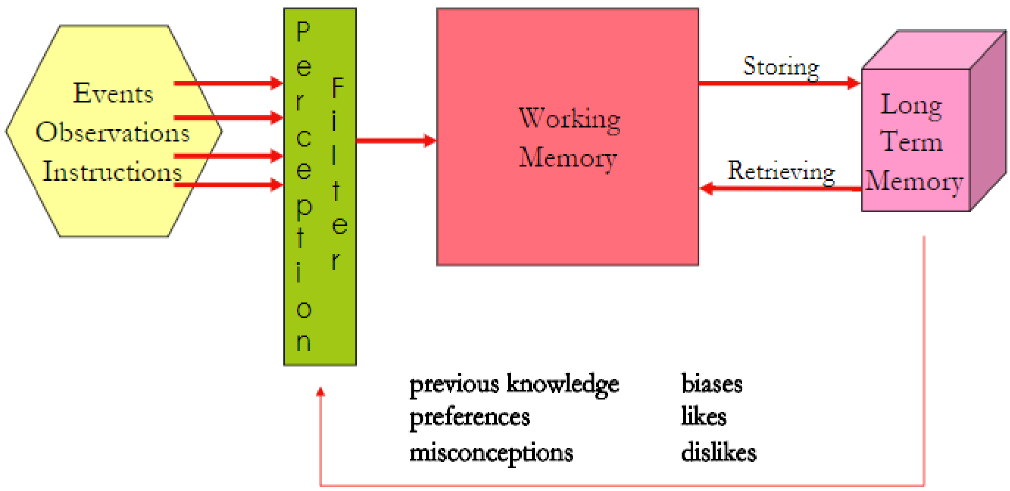

Figure 1.
Information processing theory adapted.
Source: (Pratiwi et al., 2019).

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 the 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 (Langer et al., 2017), influence learner's educational attainment. In summary, in order to learn and retain instructional materials effectively, the 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 through comparing with prior experiences in the working memory and finally meshed into new knowledge and stored in the long-term memory

4. Methodology

Creswell and Clark (2017) explain that research design is a blueprint bringing together different parts of a study in a clear and logical way to solve the research problem effectively. In this study, a non-equivalent pre-test, post-test, and delayed post-test control group design was used to carefully examine the effects over time. This design encompasses studying the same participants before and after the intervention (Libata et al., 2023). This design was used in countless ways, provided that participants were first assessed before the intervention (pre-intervention) and then reassessed afterward (post-intervention) to determine its effectiveness. This design was preferred as it was the most appropriate design to measure the effect, the intervention had on the grade 6 learners' conceptual understanding. The details of the design are shown in table 1.

Table 1.
Non-equivalent control group design.

Group	Pre-test	Intervention	Post-test	Delayed post-test
Group A	→ O_1	→ X_1	→ O_2	→ O_3
Group B	→ O_1	→ X_2	→ O_2	→ O_3
Group C	→ O_1	→ X_1	→ O_2	→ O_3
Group D	→ O_1	→ X_2	→ O_2	→ O_3
Time	Three weeks			After four weeks

Note: Group A: Experimental group1, Group B: Control 1, Group C: Experimental group 2, Group D: Experimental group 2, X_1: Treatment (SOM PHET simulation), X_2: Treatment (traditional teacher centred)

The target population of this study was all grade 6 NS/Tech learners in primary schools of South Africa. The accessible population were sixty-four grade six learners of four public primary schools in UMkhanyakude district in the KwaZulu-Natal province of South Africa. The gender distribution of the research sample (n = 64) of grade six Natural Sciences participants (59% females and 41% males). A total number of thirty-eight females and twenty-six males took part in this study. This gives us a good gender equity, which generated rich information. The four primary schools were randomly selected and assigned to two experimental and two control groups. The experimental groups were taught using a State of Matter PhET simulation while the control group were taught using traditional teacher-centered instruction approach in respect of the study's variables. The dependent variables were learners' test scores from pre-test, post-test, and delayed post-tests while the independent variable was the use of a PhET simulation.

The main instrument for data collection was the phase change of matter test (PCMT). PCMT was developed by the researcher to illicit students' conceptual understanding of phase changes of matter. The test consisted of ten two-tier multiple-choice questions. The phase change of matter concepts covered in the PCMT was evaporation, melting, and condensation. Two-tier multiple-choice questions were made up of content-based questions (first tier), Interpretation (second tier). The development of the (PCMT) was further guided by (Yan & Subramaniam, 2018), who suggest that students' responses in the normal multiple-choice test do not ordinarily show the interpretation of the questions. Kelly and Hansen (2017) claimed that in multiple-choice questions students tend to guess and overestimate their knowledge. In a two-tier multiple choice, the first tier examines factual knowledge, and the second tier justifies the reason behind the first-tier choice, thus collecting more information on the students' choices thereby determining the nature of their knowledge and understanding. Two-tier multiple-choice questions overcome the limitations of one-tier multiple-choice questions. In one tier, it is difficult to tell whether a correct response reflects a good understanding or is based on guesswork (Blown & Bryce, 2017).

In literature, Ozmen (2011) used a two-tier multiple choice (2TMC) test for conceptual understanding of chemical kinetics. One disadvantage of the 2TMC was reported by Kelly and Hansen (2017), who argued that a correct answer accompanied by a wrong explanation could either mean a lack of conceptual knowledge or guessing. It is not possible to differentiate between the two. Two marks were allocated if a learner got both tiers correct.

The first stage of the instrument development involved defining the content boundaries of 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 and 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. The distractors were based on studies reported by (Ayas et al., 2010; Aydeniz & Kotowski, 2012). Questions 1-10 were based on phase change of matter which included evaporation, melting, condensation and freezing.

In this study, content validity was defined as the extent to which the diagnostic questionnaire on phase changes of matter adequately represents the topic's breadth and depth. To assess content validity, the Phase Change of Matter Test (PCMT) was reviewed by six primary school Natural Sciences and Technology teachers. The validity was established by aligning the test content with the objectives outlined in the CAPS Natural Sciences and Technology policy document and presenting these to the educators to ensure it was within the curriculum's scope. Additionally, the teachers assessed the face and construct validity of the test items. They evaluated the ten PCMT items for their appropriateness for primary school learners and their alignment with the NCS Natural Sciences curriculum, rating each item as 'suitable,' 'not suitable, should be corrected,' or 'not suitable.' Teachers were also asked to complete a checklist (yes or no) and provide comments on each question. This checklist was designed based on factors influencing the validity of a measuring instrument (Yan & Subramaniam, 2018):

- The questions test learners' understanding of phase changes in matter.
- Ambiguous and confusing test items were avoided to prevent learners from misinterpreting the questions.
- Test takers should use vocabulary at the right level of difficulty.
- Ensuring that each question has only one unequivocal intended response in each tier.

After taking into account feedback from primary school teachers, the test was adjusted to better meet their suggestions. The reviewers confirmed that the revised diagnostic tool effectively measures students' understanding of phase changes of matter. We used the same test for the pre-test, post-test, and delayed post-test. According to Creswell (2018), an instrument's reliability is demonstrated when it consistently produces the same results under similar conditions. The pilot test showed a Cronbach's alpha reliability of 0.75, which is considered acceptable for group assessments (Zhao & Gallant, 2012). This reliability coefficient aligns well with those reported for similar two-tier tests in existing literature (Kelly, 2014; Tsui & Treagust, 2010).

To analyse the data, descriptive statistics via the measures of central tendency which include the mean was used to determine the mean difference between the pre-test and post-test scores. The purpose of the comparison between pre-test and post-test scores was to establish the statistically significance of the two instruction methods. Also, the Delayed Post-Test Scores Comparison (t-test) was performed to assess the long-term retention of knowledge that students have gained following an intervention. This test was administered four weeks after the initial learning period to evaluate how effectively students retained the concepts.

5. Results

Table 2 presents the mean pre-test scores for both the control and experimental groups. It can be observed that mean scores for both control (62.95) and PhET (70.12) groups increased indicating that learners performed better in the post-test, as compared to the pre-test. A variation of the mean, the trimmed mean, which drops 5% of the highest and lowest scores was calculated. A trimmed mean, unlike the arithmetic mean, is resistant, and is not affected by extreme values. The trimmed means were almost the same for both the pre-test and post-test respectively. This implies that the test scores were not affected by the extreme values. Therefore, the extreme scores had no significant influence on the mean. The value for the standard deviation for the pre-test was calculated as 6.132, while the standard deviation for the post-test is 6.884. Hayley et al. (2014) suggest that a higher standard deviation indicates that scores are more spread out around the mean, while a lower standard deviation shows that scores are closer to the mean. The standard deviation slightly increased from the pre-test to the post-test. Based on the descriptive statistics, it can be concluded that learners' performance improved slightly in the post-test compared to the pre-test.

The data underwent further analysis, including tests for Skewness and Kurtosis. For the experimental group, the calculated skewness for the pre-test and post-test were 0.068 (SE 0.215) and 0.701 (SE 0.215), respectively. This indicates that the scores were symmetrically distributed around the mean. In contrast, the skewness values for the control group's pre-test and post-test were -0.115 (SE 0.243) and 1.264 (SE 1.132), respectively, suggesting that the scores were negatively skewed, or skewed to the right.

Table 2.
Descriptive statistics of pre-test and post-test scores.

			Pre-test		Post-test	
Group			**Statistic**	**Std. error**	**Statistic**	**Std. error**
Control	Mean		54.37	0.538	62.73	0.536
	95% confidence interval for mean	Lower bound	55.33		63.87	
		Upper bound	57.41		65.63	
	5% trimmed mean		53.43		62.95	
	Median		57.00		60.00	
	Variance		37.714		39.132	
	Std. deviation		6.134		6.882	
	Minimum		46		44	
	Maximum		72		76	
	Range		26		32	
	Interquartile range		5		6	
	Skewness		-0.115	.243	-0.064	0.216
	Kurtosis		1.264	.467	1.132	0.413
PhET	Mean		55.86	.589	70.30	0.539
	95% confidence interval for mean	Lower bound	53.69		71.04	
		Upper bound	55.02		70.17	
	5% trimmed mean		54.84		70.12	
	Median		54.00		64.00	
	Variance		43.948		48.212	
	Std. Deviation		6.033		7.025	

	Minimum	40		45	
	Maximum	75		80	
	Range	35		25	
	Interquartile range	7		9	
	Skewness	0.041	0.235	0.068	0.230
	Kurtosis	0.368	0.438	0.701	0.473

Another test statistics conducted was The Delayed Post-Test Scores Comparison (t-test) is performed to assess the long-term retention of knowledge that students have gained following an intervention. This test was administered four weeks after the initial learning period to evaluate how effectively students retained the concepts. Table 3 compares the delayed post-test scores of two groups: the control group, taught through a traditional teacher-centered approach, and the experimental group, which utilized the PhET simulation method. The control group (N = 32) achieved a mean score of 53.91 with a standard deviation of 6.558, while the experimental group (N = 32) had a higher mean score of 60.39 with a standard deviation of 6.369. The t-test result of 5.349 with 63 degrees of freedom reveals a statistically significant difference between the scores of the two groups ($\alpha < 0.05$). Based on these results, the null hypothesis (H0), which posits no significant difference between the groups, could not be accepted.

Table 3.
Delayed post-test scores comparison (T-test).

Group	N	Mean	Std. deviation	Std. Error Mean	t	df
Control	32	53.91	6.558	0.595	5.349	63
Experimental	32	60.39	6.369	0.558		

Source: ($\alpha < 0.05$)

6. Discussion

This study revealed a statistically significant improvement in the mean scores of Grades 6 learners who were taught using a PhET simulation, compared to those who received traditional instruction. To assess if there was a notable difference in pre-test scores between the experimental and control groups, an independent samples t-test was performed. The results indicated no significant difference between the two groups' pre-test scores, with the control group averaging 53.43 and the experimental group averaging 54.84. However, both groups showed improvement in their post-test scores, with the control group averaging 62.95 and the PhET group 70.12. These higher post-tests mean scores suggest that the PhET simulation intervention was more effective, leading to better performance than the traditional instruction. The findings match those of Serevina and Raida (2021), who found that simulations play a key role in helping students better understand complex scientific concepts.

Moreover, even though the PhET simulation was used as a demonstration by teachers rather than being directly manipulated by the students, the post-test mean scores were still notably high. This finding aligns with Ndihokubwayo et al. (2020), who noted that computer simulations, whether used interactively or as demonstrations, can enhance instructional effectiveness. Their research also indicates that the outcomes are similar whether students engage with the simulation themselves or simply observe it. These results suggest that the PhET simulation effectively enhances students' understanding of complex chemical concepts, such as phase changes of matter. Furthermore, this indicates that a strong conceptual grasp is a key predictor of success in science education (Schwedler & Kaldewey, 2020).

The findings of this study have an impact on the modified Johnstone triangle by (Taber, 2013). Conceptual understanding of phase change of matter may shift among all the three levels macro, representation and sub-microscopic levels or domains. The finding on the high mean scores from the PhET groups confirmed the existence of some improvement in learners' conceptual understanding of the phase change of matter at large. The conceptual understanding impacts positively learners' constructing knowledge about phase changes. The results seem to suggest that learner performance is influenced by instructional approaches. Therefore, it can be established that simulations enhanced learners' performance and could improve the retention of phase change of matter concepts. These findings support the argument that simulations can improve academic performance and help learners retain concepts in phase change of matter (Mohafa et al., 2022). 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.

7. Recommendations

Encourage students to get hands-on with simulations instead of just watching them being demonstrated. When students actively engage with the tools, they learn more deeply and see better results.

Future researchers should test simulation-based learning in different schools and subjects to see if it works well in various settings.

Also, comparative study could be conducted examine how simulation-based learning stacks up against other modern teaching methods, like gamification or blended learning. This can help to figure out which strategies work best for different learning goals.

The Department of Education should offer training and resources to help teachers incorporate simulation-based learning and innovative tools into their classrooms effectively.

8. Conclusion

The study showed that using the PhET simulation greatly enhanced Grade 6 students' understanding as against the traditional teaching methods. This is because the group using the PhET simulation had noticeably higher post-test scores, highlighting that this method was more effective in deepening their understanding. This aligns with the key principles of Information Processing Theory (IPT), which emphasize the effectiveness of using simulations in teaching and learning. IPT suggests that learners grasp and remember concepts better when they actively engage with the material. Operating on the IPT principles, the PhET simulation allowed students to explore complex topics, like phase changes, in a more dynamic and visual way, which made it easier for them to understand and retain the information.

The significance of simulation was further demonstrated by the teachers to enhance learners' understanding of concepts. This suggests that interactive and thoughtfully designed educational tools, like simulations, can significantly boost how students process information and learn. The study highlights the need to invest in educational technology and infrastructure. By incorporating tools like simulations, education systems can innovate and improve how students learn, aligning with global education policies that encourage the use of technology to advance learning.

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