Multimodal Technologies and Interaction

Article

Transforming Science Education in Elementary Schools: The Power of PhET Simulations in Enhancing Student Learning

Hussam Diab [1,*], Wajeeh Daher [2,3,*], Baraa Rayan [4], Nael Issa [5] and Anwar Rayan [6]

1 Educational Systems Management Program, Faculty of Graduate Studies & Science Department, Al-Qasemi Academic College, Baka EL-Garbiah 3010000, Israel
2 Mathematics Education Program, Al-Qasemi Academic College of Education, Baqa 3010000, Israel
3 Graduate Studies, An-Najah National University, Nablus P400, Palestine
4 Abdo Salim School, Ibilin 3001200, Israel; b_rayan@ngsat.co.il
5 Science Department, Al-Qasemi Academic College of Education, Baqa 3010000, Israel; nael-e@qsm.ac.il
6 Science and Technology Department, Al-Qasemi Academic College of Education, Baqa 3010000, Israel; a_rayan@qsm.ac.il
* Correspondence: hussamono@gmail.com (H.D.); wajeehdaher@najah.edu or wdaher@qsm.ac.il (W.D.)

Abstract: In recent years, the integration of technology into education has significantly transformed teaching methods, especially in science education. Tools like PhET simulations have proven highly effective in enhancing student engagement and comprehension. Research has highlighted the value of simulation-based learning in fostering critical thinking and problem-solving skills. This study aimed to explore the impact of simulations, with a focus on PhET, on improving elementary students' learning outcomes, an area that remains under-researched. The study compared the performance of two groups of third-grade students: one group learned about solubility using PhET simulations, while the other relied on traditional textbook instruction. Each group comprised fifty students. The study lasted for a two-month period. The instructional approach was investigative learning. Data were gathered through student responses to materials science questions aligned with Bloom's Taxonomy, allowing for a detailed evaluation of their understanding and application of scientific concepts. Responses were assessed for accuracy and scored accordingly. We ran an independent-sample *t*-test to decide whether the difference in the mean score in science achievement between the two research groups was significant. The results showed that students using PhET simulations not only achieved significantly higher scores but also demonstrated their ability to explain their reasoning during problem-solving tasks. These findings emphasize the substantial advantages of incorporating digital tools like PhET simulations into elementary science education, as they enhance conceptual understanding and better equip students to tackle future scientific challenges. The present research results complement the previous research on using technology in the chemistry elementary classroom and add the issue of simulations to this research. The results of this study are centered on the topic of solubility. To broaden the generalizability of these findings, future research should examine the effects of simulations on student achievement in a wider range of elementary science topics.

Keywords: PhET simulation; elementary science education; learning outcomes; problem-solving tasks; scientific concepts

check for updates

Citation: Diab, H.; Daher, W.; Rayan, B.; Issa, N.; Rayan, A. Transforming Science Education in Elementary Schools: The Power of PhET Simulations in Enhancing Student Learning. *Multimodal Technol. Interact.* **2024**, *8*, 105. https://doi.org/10.3390/mti8110105

Academic Editor: Julius Nganji

Received: 20 October 2024
Revised: 14 November 2024
Accepted: 15 November 2024
Published: 20 November 2024

1. Introduction and Literature Review

In recent years, a broad and transformative technological revolution has impacted nearly all facets of life, including education [1–6]. Educational institutions worldwide have increasingly adopted innovative teaching methods that incorporate computers, the internet, and smartphones. These approaches aim to align with the demands of the digital age, making the learning process more interactive, engaging, and meaningful for students [7,8].

A key example of this technological revolution is the growing use of interactive simulations and digital tools in science education [9]. Simulations offer visual representations of complex scientific phenomena, allowing students to engage in investigative and dynamic learning experiences. Through digital experiments, students can manipulate variables and observe outcomes in real-time, making the process more engaging and effective than traditional methods such as reading, lectures, or short videos [10]. Additionally, simulations are powerful tools for enhancing the comprehension of intricate scientific concepts by creating an interactive environment where students can directly experience and apply their knowledge [11]. These tools also offer a multidimensional learning experience, integrating text, images, animations, and interactive elements, which together deepen students' understanding of scientific concepts and their real-world applications [12].

Virtual laboratories, such as PhET simulations, offer students the opportunity to conduct experiments digitally that many schools may lack the physical resources to support. These simulations are highly interactive and engaging, allowing students to actively explore and discover scientific concepts. They are scientifically accurate and provide dynamic, illustrative representations of complex scientific principles, aiding students in developing a deeper conceptual understanding of various topics [13].

Integrating simulations into science teaching across various age groups offers numerous advantages. Learners can manipulate variables more quickly and efficiently than with traditional instruments or methods, and simulations allow for multiple risk-free trials with immediate feedback. This approach better prepares students for future laboratory experiments while reinforcing concepts taught in the classroom. Simulations also provide exposure to advanced instrumental methods that may not be available during physical lab sessions [14]. Additionally, digital tools introduce an entertaining element to education, boosting students' motivation and interest [15]. As a result, the use of simulations, particularly in science education, enhances the overall quality of learning and contributes to improved educational outcomes [8].

1.1. Chemistry Education in the Primary School

Chemistry education at the primary school level is vital for laying a strong foundation in scientific literacy and nurturing a lifelong interest in the sciences. Introducing students to fundamental concepts such as chemical materials and their properties is key to developing critical thinking and problem-solving skills, which are essential for understanding the physical world. Early exposure to chemistry helps students grasp how materials interact, their practical uses, and their relevance in everyday life. Hands-on experiments and interactive activities are particularly effective at this stage, allowing students to observe and explore chemical reactions and properties firsthand [16].

Moreover, incorporating chemistry education into the primary curriculum stimulates curiosity and innovation by allowing students to experiment with various materials and biomaterials, including metals, polymers, and ceramics [17]. Activities such as building simple structures or testing the strength of materials significantly enhance students' understanding and retention of these concepts. Furthermore, connecting material science to real-world applications, like recycling and sustainable development, makes learning more engaging and relevant for young students [4]. Consequently, integrating chemistry education in primary schools not only enriches students' scientific knowledge but also cultivates the critical thinking and problem-solving skills essential for their future academic and professional success.

In addition, teaching chemistry in elementary school presents unique challenges and opportunities. On one hand, the complexity and abstract nature of chemical concepts can make it difficult for young students to grasp the material, as these ideas often go beyond their immediate experiences and cognitive development [18]. Young students may struggle with understanding the microscopic and symbolic representations inherent in chemistry, which can lead to misconceptions or a lack of interest in the subject. However, the integration of digital tools, such as interactive simulations, offers opportunities to enhance student understanding by providing visual representations that allow them to engage practically with complex chemical processes [19]. These tools create a more dynamic and interactive learning environment, transforming abstract concepts into tangible experiences for students.

1.2. The Use of Technology in the Chemistry Classroom

The integration of technology in the chemistry classroom has transformed the way students learn and interact with scientific concepts. Technology-enhanced learning tools, such as interactive simulations, virtual labs, and digital resources, offer dynamic and immersive experiences that traditional methods often struggle to replicate. For example, simulations enable students to visualize and manipulate molecular structures, chemical reactions, and processes in real-time, significantly improving their comprehension and retention of complex concepts [20,21].

In primary education, interactive software and apps introduce young learners to fundamental chemistry principles through gamified learning experiences, making abstract concepts more tangible and engaging [22]. These tools accommodate various learning styles and paces, ensuring that all students can effectively grasp the material.

At the secondary level, virtual laboratories allow students to conduct experiments in a safe, controlled environment, promoting inquiry-based learning and critical thinking skills. These virtual labs can simulate hazardous or impractical experiments that would not be feasible in a traditional classroom, thus expanding students' learning opportunities [23]. Additionally, online platforms and digital resources provide access to up-to-date scientific research and data, allowing students to explore contemporary advancements in chemistry and understand their real-world applications [24].

Overall, the integration of technology in chemistry education enhances student engagement, fosters a deeper understanding of scientific concepts, and equips students with the tools and methodologies needed for future scientific endeavors.

Technological tools have not only advantages but restrictions too. Technological tools may exacerbate accessibility issues, especially in under-resourced schools where students often lack adequate access to digital devices and reliable internet [25]. Addressing these disparities is essential to ensure equitable learning experiences and maximize the benefits of simulation-based education across diverse educational settings. UNESCO's recent report by West [26], further raises concerns about the rapid adoption of educational technologies and their impact on learning effectiveness, accessibility, and equity. Experiences during the COVID-19 pandemic underscored how technological reliance in education led to widening inequalities, a decline in student and teacher well-being, and potential privacy risks due to increased data collection and surveillance. These observations highlight the need for careful, context-sensitive technology integration that does not compromise educational quality.

1.3. The Use of Simulations in Elementary Science Education

Simulations have become a valuable tool in science education, offering a way to visualize and interact with scientific concepts that might otherwise remain abstract. PhET simulations have proven particularly useful in elementary science classrooms. These simulations are interactive, visual, and accessible, providing both teachers and students with tools to better understand complex scientific principles [27]. By enabling students to engage with content through virtual experiments, PhET simulations offer immediate feedback and a hands-on learning experience in a digital format, which helps bridge the gap between theoretical knowledge and practical application [28,29].

In elementary science education, traditional methods often rely heavily on static visuals and text explanations, which can be challenging for young students. Simulations, in contrast, support active learning by allowing students to manipulate elements and see real-time results, thereby reinforcing their understanding through both visual and kinesthetic engagement [30]. Studies have shown that such interactive simulations increase students' motivation and improve their retention of scientific concepts, making learning both enjoyable and effective [31,32]. Prior research supports the efficacy of simulations in enhancing comprehension and fostering positive attitudes toward science learning. For instance, Astuti et al. [30] found that students who used interactive simulations demonstrated improved critical thinking skills and a greater ability to apply scientific concepts in various contexts

Furthermore, simulations align with constructivist learning theories, which emphasize that knowledge is constructed through active engagement and connection with prior knowledge. PhET simulations, by providing a controlled environment for experimentation, encourage collaborative discussions, hypothesis testing, and direct observation. This approach supports students' deeper understanding and helps clarify abstract scientific principles [32].

1.4. Bloom's Taxonomy and Science Education

Bloom's Taxonomy is a hierarchical framework used to classify educational learning objectives based on complexity and specificity. Originally developed by Benjamin Bloom in 1956 and revised in 2001 by Anderson and Krathwohl [33], this model outlines six cognitive process levels: remembering, understanding, applying, analyzing, evaluating, and creating. Each level builds upon the previous one, promoting a progressively deeper and more comprehensive understanding of the subject matter.

Incorporating Bloom's Taxonomy into science education encourages students to go beyond rote memorization and develop higher-order thinking skills. By advancing through these levels, students enhance their critical thinking and problem-solving abilities, which are essential for scientific inquiry and grasping complex concepts [34]. This structured approach not only improves learning outcomes but also equips students with the analytical and creative skills necessary to tackle real-world scientific challenges [35].

The objective of this study was to evaluate the impact of integrating PhET simulations into science lessons on elementary school students' ability to solve chemistry problems. The study focuses on assessing students' cognitive development across different levels of Bloom's Taxonomy. The performance of students using PhET simulations is compared to those relying solely on traditional methods. The questions addressed in this research pertain to the topic of solutions and solubility, a core element of the elementary school science curriculum.

1.5. The Influence of Simulations on Students' Thinking Within Bloom's Taxonomy

Simulations serve as powerful tools for developing a range of cognitive skills across Bloom's Taxonomy, from foundational knowledge recall to advanced evaluation and creative thinking. At the foundational levels of remembering and understanding, simulations support students in recalling and comprehending scientific concepts by presenting them in interactive and visually engaging formats that enhance retention [36]. For instance, PhET simulations provide visual representations of scientific phenomena, allowing students to explore abstract concepts, such as energy transfer or molecular interactions, in a manner that fosters comprehension and reinforces learning [37].

As students move to higher levels, including applying and analyzing, simulations offer opportunities to manipulate variables and explore cause-and-effect relationships, facilitating critical thinking and analytical skills [30]. Through real-time experimentation within the simulation, students can test hypotheses and observe immediate outcomes, fostering a deeper understanding of scientific principles and enhancing their ability to analyze complex systems [38].

At the upper levels of evaluating and creating, simulations encourage students to critically evaluate data, make evidence-based decisions, and construct new models or hypotheses. For example, simulations can be used to predict the effects of changing a variable, assess the accuracy of these predictions, and refine understanding based on outcomes [39]. This iterative process of experimentation and reflection allows students to engage in creative problem-solving and hypothesis generation, culminating in the highest levels of Bloom's Taxonomy, where they design their own experiments and develop new insights [40]. By creating an adaptive, inquiry-based learning environment, simulations like

PhET not only reinforce content knowledge but also cultivate critical and creative thinking across all cognitive levels.

1.6. Research Rationale and Goals

In a previous study, we conducted a qualitative analysis to observe how third-grade students collaborated in small groups (pairs and trios) while using PhET simulations. These students were tasked with exploring specific science topics and responding to related questions. Their responses were analyzed through the lens of Bloom's Taxonomy, focusing on different cognitive levels such as remembering, understanding, applying, analyzing, evaluating, and creating. In this research, we extended the investigation by comparing the performance of two groups: an experimental group using PhET simulations and a control group relying solely on traditional textbook methods. We evaluated the students' responses by assigning scores based on accuracy and depth of explanation, and we also computed the frequencies of different types of responses, providing illustrative examples.

The present study complements our previous work, triangulating the findings to offer a comprehensive view of elementary students' learning in chemistry through simulations. Understanding science at the elementary level is crucial, as it lays the foundation for students to pursue scientific studies in middle and secondary education [41]. This research highlights the effectiveness of incorporating simulations in primary school science lessons, offering insights that can assist teachers and educational policymakers in developing science curricula that integrate digital tools like PhET to enhance student learning outcomes.

In addition to the above, previous research primarily offered qualitative insights or concentrated on older learners; the present study quantitatively assesses the impact of PhET simulations on elementary students' cognitive engagement across Bloom's Taxonomy. The findings will help provide robust support for the integration of digital simulations in primary science education.

1.7. Research Questions

1. Does learning with the PhET program result in significant differences in students' knowledge scores between the PhET group and the regular group?
2. What are the differences in students' answers to chemistry questions between the PhET group and the control group, particularly in terms of accuracy, explanation depth, and cognitive engagement?

2. Materials and Methods

2.1. Research Context and Participants

The context of the research is that of primary school chemistry. The study involved 100 third-grade students, divided into two groups. The experimental group, consisting of 50 students, learned the topic of solubility using PhET simulations, while the control group of 50 students studied the same topic using only the third-grade chemistry textbook. The mean score of students' age was 9.34 years with standard deviation of 0.25 years. In the experimental group, there were 24 female students and 26 male students, while in the control group, there were 27 female students and 23 male students. The sampling method started as that of convenience, where we chose a school where a chemistry teacher agreed to participate in the research, and where the same teacher would teach the experimental and the control groups. The distribution of experimental and control groups was done randomly.

The third-grade chemistry book includes the following topics: 1. Materials: properties and uses (Material properties and ways to identify them; solubility in water—solvent and solute, electrical conductivity, magnetism, flammability, heat conductivity; material mixtures and ways to separate them. Distinguishing properties: water solubility, color, floatation, magnetism, grain size). 2. Use of materials: The relationship between the properties of the material and its use (Solubility: preparation of drinks and detergents. Electrical conductivity: operation of electrical devices. Magnetism: grip of iron tools/bodies. Combustion: producing heat for cooking and heating and producing light for lighting). 3. Material changes: Combustion of materials (Conditions for combustion: ignition temperature, oxygen, and fuel. Combustion materials: wood, coal, kerosene, oil, and more. Combustion products: materials—ashes, gases, and smoke. Energy—light and heat. 4. Materials: benefit and environmental price (The importance of fuels for cooking, lighting, heating, operating machines and cars, generating electricity. The environmental price of fuel utilization—air pollution (smoke, gases and ash), fuel leakage into the environment. Solutions to reduce environmental damage—chimney filters, reducing the use of private vehicles, saving electricity. Adopting responsible environmental behavior to preserve the quality of the environment—saving electricity, reducing the use of vehicles for example).

The study lasted for a two-month period. The students learned 32 lessons, where each lesson lasted for 45 min. The instructional approach was investigative learning. To avoid confounding variables, the same teacher taught both the experimental and the control groups. In the simulations' class, the teacher displayed a simulation using a projector to demonstrate the concept of solubility to the students. Doing that, she showed examples of the solubility of various substances, such as sugar and salt. Using the simulation, the teacher highlighted the amount of solute, explaining the concept of saturation. Afterwards, the students practiced what they had learned individually. Each student accessed the simulation and, with the teacher's guidance, adjusted parameters such as the amount of solute, the amount of solvent, and observed how the change of these parameters affected solubility. At the end, the teacher conducted a concluding discussion to ensure the consolidation of students' understanding.

We chose to compare the simulation instructional method to that of the book method because generally elementary schools' students learn chemistry by the book, which make researchers compare the innovative or new instructional method to that of the book method (ex., [29,30]).

2.2. The PhET Simulations

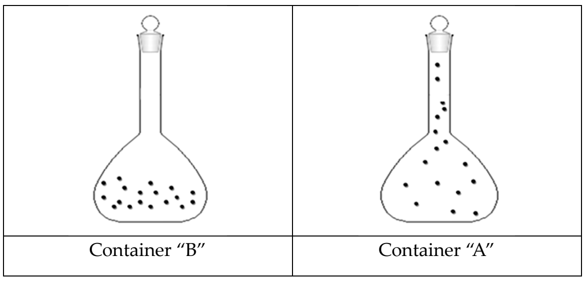
The PhET simulations used in this study are composed of small modules specifically designed for scientific exploration, each focusing narrowly on a single activity or lesson. These modules can be seamlessly integrated into classroom instruction or accessed on students' digital devices. Each simulation includes a virtual representation of physical objects that can be manipulated by the user, along with "disciplinary representations" that connect the activity to scientific discourse [41].

The PhET project provides over 160 simulations across subjects such as physics, chemistry, mathematics, earth science, and biology. These simulations are free and open-licensed, available for online use or downloadable for offline use with minimal preparation required from teachers and students. Designed for all educational levels from primary to postsecondary, the project is based at the University of Colorado and widely supported by foundations as well as commercial, governmental, and educational organizations. It should be noted that most of the research and applications of these technologies have so far focused on secondary and higher education. Despite their numerous advantages and benefits, there remains a lack of studies and a knowledge gap in the published literature, particularly concerning elementary education.

2.3. Data Collection Tools

In the present study, we used two collecting tools. Both tools concerned the texts of students' solutions to 12 chemistry problems related to Bloom's Taxonomy levels: remembering, understanding, application, evaluation, and creation. The first tool is concerned with the accuracy type of the answer, as well as the justification given, while the second tool is concerned with the answers' score, i.e., with the students' achievement related to the problems' answers. Table 1 includes an example of a problem from each Bloom's level. The questions given to the third-grade students were 2 from each Bloom's level, where the score of each level was computed as the mean of the scores of the two questions from the same level.

Table 1. Examples of the chemistry problems given to the students.

Level	Problem
Remembering	We dissolved sugar in water. What is the solvent and what is the solute?
Understanding	Nader added 20 g of sugar to 100 g of water and stirred. After the stirring, an amount of sugar precipitated at the bottom of the container. Explain why the whole amount of sugar in the container did not dissolve.
Application	Salwa added 25 g of salt to 120 g of water and stirred. After stirring an amount of salt precipitated at the bottom of the container. Suggest a method to dissolve all the salt at the bottom of the container.
Analysis	The students in the fifth grade wanted to examine the relationship between the size of water and the amount of heat requested to raise the temperature of the water. To determine this relationship, the students poured 100 mL of water into a container and 1000 mL of water into another container made of the same material. They put the two containers on two similar heat sources. They measured the temperature of the water in the 100 mL container and obtained a temperature of 58 °C. Does this temperature prevail also in the 1000 mL container? Explain.
Evaluation	Yousef dissolved a teaspoon of sugar in a cup of water and a sugar solution was produced. The solution was too sweet to drink. Propose a method to reduce the sugar concentration in the solution. Support your proposal with scientific evidence proving its validity.
Creation	When Noor added a teaspoon of salt to a glass bowl filled with water, the salt dissolved completely in the water. If we assume that salt particles dissolved in water look like small black balls, and Noor had magic glasses to help her see these black balls, which of the following two containers (Container A or Container B) correctly represents the solution resulting from dissolving salt with water? Explain why. 

2.4. Data Analysis Tools

To evaluate students' understanding of the solubility topic, each problem's answer was given 10 if the answer was correct and the explanation was correct. The answer was given 5 if it or the explanation was correct but not both of them. The answer was given 0 if neither the answer nor the explanation was correct. The answer took also the 0 score if the student gave no answer.

2.4.1. An Example of Assessing a Problem's Answer

The problem: Nader added 20 g of sugar to 100 g of water and stirred. After stirring, an amount of sugar precipitated at the bottom of the container. Explain why the whole amount of sugar in the container did not dissolve.

An answer that took the score 0:
No answer, we did not put enough water in the container.
An answer that took the score 5:
We did not stir enough.
An answer that took the score 10:
The solution reached its saturation point.

2.4.2. Statistical Analysis

We computed the means and standard deviations for the achievement scores of the experimental and control groups. Afterwards, we ran an independent-sample *t*-test to decide whether the difference in the mean score in science achievement between the two research groups was significant.

2.5. Validity and Reliability of the Methodology

The reliability of the methodology arises from the agreement between coders regarding the analysis process of the themes of students' answers (accuracy of the answers). Three coders coded students' responses and we computed the agreement between the coders, giving values between 0.88 and 0.92 for the responses to have 0, 5 or 10 score. These values indicate the validity of the analysis, and therefore its reliability. The agreement value was obtained through computing the Holsti equation: PA (Holsti) = 2A/(N1 + N2), where PA (Holsti) represents percentage of agreement between two coders; A is the number of the two coders' consensus decisions, and N1 and N2 are the numbers of decisions the coders have made, respectively.

The validity of the coding process was initially established by resolving disagreements between the three coders. This resolution occurred through discussion sessions where the three coders went through their initial categorization, comparing and discussing it until they arrived at agreement.

3. Results

The results are two parts referring to the two research questions.

3.1. The First Research Question

The first research question examined whether learning with the PhET program results in significant differences in students' knowledge scores in all Bollom's levels between the PhET group and the regular group. We computed means and standard deviations of the scores of the two groups, and to find the significance of the differences between the scores of the two groups, we ran independent-sample *t*-test.

The two groups did not differ significantly in their achievement before the experiment, where this achievement was represented by the overall students' achievement in the last trimester (2022–2023). The mean of students' achievement in the PhET group was 9.31 (SD = 0.53), while the mean of students' achievement in the control group was 9.28 (SD = 0.65), $t(98) = 0.25$, $p = 0.80$.

Table 2 describes means and standard deviations of students' scores in the levels of knowledge according to Bloom's Taxonomy after the experiment. Table 2 also shows the significance of the differences between the scores of the experiment and the control groups in all Bollom's levels.

Table 2. Means and standard deviations of students' scores in the levels of knowledge after the experiment.

Level	Group	M	SD	*t*-Test	*p*
Remembering	Experiment Control	9.300 6.500	1.679 3.536	5.059	<0.001
Understanding	Experiment Control	9.500 6.350	1.515 3.820	5.420	<0.001

Table 2. *Cont.*

Level	Group	M	SD	*t*-Test	*p*
Applying	Experiment Control	9.200 6.300	1.856 3.753	4.899	<0.001
Analyzing	Experiment Control	9.200 3.650	1.552 3.787	9.590	<0.001
Evaluation	Experiment Control	8.250 3.200	3.041 3.713	7.440	<0.001
Creating	Experiment Control	7.650 5.150	3.171 3.171	3.942	<0.001

Table 2 shows that the means of the levels of knowledge of the experiment group are higher than those of the control group and these differences are significant at the level of 0.001. The difference between the two groups was higher in the case of analyzing and evaluation levels, indicating the effectiveness of the PhET simulation to boost high-level knowledge.

3.2. The Second Research Question

The second research question examined students' answers to the chemistry questions, comparing between them. Following are those answers for the questions related to the knowledge levels.

3.2.1. The Remembering Question

We dissolved sugar in water. What is the solvent and what is the solute?

Forty-five students in the PhET group accurately answered the remembering question, saying that the water is the solvent, and the sugar is the solute. Five students in the PhET group inaccurately exchanged between water and sugar.

Forty-one students in the control group accurately answered the remembering question, while nine students in the control group inaccurately answered the question.

3.2.2. The Understanding Question

Nader added 20 g of sugar to 100 g of water and stirred. After the stirring, an amount of sugar precipitated at the bottom of the container. Explain why the whole amount of sugar in the container did not dissolve.

Table 3 describes the students' answers to the understanding question in both research groups, as well as the frequency of each answer.

Table 3. Students' answers to the understanding question and frequency of each answer.

Answer	Frequency
PhET group	
The water reached saturation level	10
A saturation process has occurred	10
He did not stir well	5
He added a big amount of sugar, so saturation was reached	10
The water was a small amount	5
He added a lot of sugar	4
The solution reached saturation	6
Control group	
It is a lot	10
The amount of sugar was big.	10
The amount of sugar was more than the water	20
The water amount was bigger	4
It is difficult for the sugar to dissolve in the water	6

Table 3 shows that the students in the PhET group gave more accurate answers than the students in the control group. In addition, the students in the PhET group gave more explanations than the students in the control group. For example, the students in the PhET group used the idea of saturation in their explanations, while the students in the control group did not.

3.2.3. The Application Question

Salwa added 25 g of salt to 120 g of water and stirred. After stirring, an amount of salt precipitated at the bottom of the container. Suggest a method to dissolve all the salt at the bottom of the container.

Table 4 describes the students' answers to the understanding question in both research groups, as well as the frequency of each answer.

Table 4. Students' answers to the application question and frequency of each answer.

Answer	Frequency
PhET group	
We add warm water to the solution	7
We add water to the solution	30
We add warm water	2
We add hot water to accelerate the dissolving of the salt	10
No answer	1
Control group	
We add water to the cup	21
We add water	
She added a lot of salt	13
No answer	13

Table 4 shows that only one student in the PhET group did not answer the question, while thirteen students in the control group did not answer the question and another third student in the control group answered it inappropriately. In addition, the students in the PhET group used the idea of 'warm or hot water' in their explanation, while the students in the control group did not.

3.2.4. The Analysis Question

The students in the fifth grade wanted to examine the relationship between the size of water and the amount of heat needed to raise the temperature of the water. To determine this relationship, the students poured 100 mL of water into a container and 1000 mL of water into another container made of the same material. They put the two containers on two similar heat sources. They measured the temperature of the water in the 100 mL container and obtained a temperature of 58 °C. Does this temperature prevail also in the 1000 mL container? Explain.

Table 5 describes the students' answers to the analysis question in both research groups, as well as the frequency of each answer.

Table 5. Students' answers to the analysis question and frequency of each answer.

Answer	Frequency
PhET group	
No because the two amounts are not equal	25
No because the big amount needs more time to heat than the small amount	11

Table 5. *Cont.*

Answer	Frequency
No because the second container has a bigger amount of water, so it needs more time.	4
No	8
No answer	2
Control group	
No. The quantity of water is not equal.	12
No	2
Yes, because the container is made of the same material	20
Yes	5
No answer	10

Table 5 shows that here too, more students in the PhET group answered the question than in the control group. In addition, forty students in the PhET group gave accurate explanations in their response, while only twelve students in the control group did so.

3.2.5. Evaluation Question

Yousef dissolved a teaspoon of sugar in a cup of water and a sugar solution was produced. The solution was too sweet to drink. Propose a method to reduce the sugar concentration in the solution. Support your proposal with scientific evidence proving its validity.

Table 6 describes the students' answers to the evaluation question in both research groups, as well as the frequency of each answer.

Table 6. Students' answers to the evaluation question and frequency of each answer.

Answer	Frequency
PhET group	
Adding more water to the solution so that the sugar is distributed over a larger amount of water	22
Adding more water, as we did in the simulation (when we added water to the solution of water and sugar, the color became lighter because the sugar was distributed over a larger amount of water)	7
Adding water to the solution reduces the sweetness of the solution because the sugar will dissolve in a larger amount of water	9
Adding more water reduces the sugar taste	11
No answer	1
Control group	
Add water to the cup	15
Add water	2
Evaporate water	18
No answer	15

As in the previous knowledge levels, here too, the number of students who answered inaccurately or did not answer the evaluation question in the control group is far more than the number in the PhET group. In addition, the students in the PhET group gave detailed explanations (38 out of 50), while in the control group, the students did not pay attention to explanations.

3.2.6. Creation Question

When Noor added a teaspoon of salt to a glass bowl filled with water, the salt dissolved completely in the water. If we assume that salt particles dissolved in water look like small black balls, and Noor had magic glasses to help her see these black balls, which of the following two containers (Container A or Container B) correctly represents the solution resulting from dissolving salt with water? Explain why.

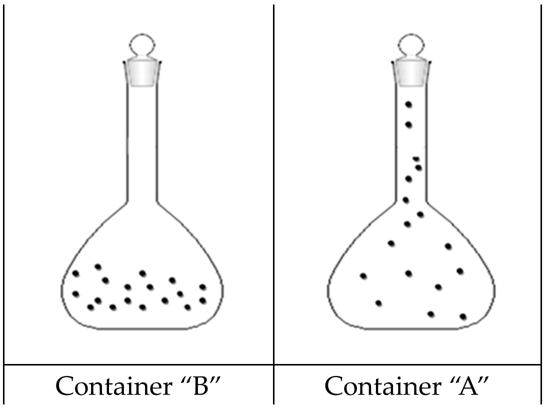


Table 7 describes the students' answers to the creation question in both research groups, as well as the frequency of each answer.

Table 7. Students' answers to the creation question and frequency of each answer.

Student Answer	Frequency
PhET group	
Container A because the solute spreads throughout the liquid.	18
Container A, the salt spread in the container because it dissolved in the water. When we added red salt to the water, the color of all the water changed because the salt dissolved throughout the water and not just in part of it.	15
Container A, the salt dissolves in all of the water. If there is saturation, it will not be like picture B because the salt must be in all of the water, and it must also precipitate at the bottom of the container only.	8
Container A	3
Container A, when the sugar drops into the water, it spreads everywhere.	2
No answer	4
Control group	
Container A, the salt is in all the water	20
Container A, the salt is all over the container	5
Container A	15
Container B, because the salt is at the bottom of the bowl; when we conducted the experiment in class, the salt remained at the bottom of the container and was not in all the water	6
Container B, because salt precipitated.	2
No answer	2

Table 7 shows that the two groups were almost similar in answering accurately and inaccurately the creation question (46 answers were accurate in the PhET group, while 40 answers were accurate in the control group). The main difference between the two groups was in the inclusion of explanations. The answers in the PhET group included explanation more than in the control group. Those explanations were detailed in the case of the PhET group.

4. Discussion

In answering the remembering question, students in the PhET group exhibited a slightly higher accuracy rate compared to the control group (45 students in the PhET group versus 41 students in the control group). This suggests that the PhET simulations provided a slight advantage in aiding students' retention of basic information.

For the understanding question, both groups provided a range of explanations for why not all the sugar dissolved. However, students in the PhET group offered more accurate and varied explanations, demonstrating a deeper grasp of key concepts such as saturation, stirring, and the ratio of solute to solvent. This suggests that the visual and interactive nature of the PhET simulations helped students better visualize and comprehend the chemical processes involved, as supported by similar findings in previous research [9].

At the application level, students in the PhET group demonstrated a solid understanding of saturation and its role in dissolving solutes. Their responses showed that they could effectively apply their knowledge of solubility to real-world chemistry problems. In contrast, responses from the control group indicated a more superficial understanding, with many students focusing on the quantity of the solute (using terms like "a lot") rather than the scientific concept of saturation. This deeper comprehension in the PhET group underscores the effectiveness of simulations in enhancing students' conceptual understanding, a result in line with prior research on PhET simulations [41].

Responses to the analysis question revealed different levels of understanding between the two groups. While both groups showed some recognition of the need for additional water to dissolve salt and the differences in heat transfer between various volumes of water, students in the PhET group demonstrated twice the level of recognition regarding the role of volume compared to the control group. This enhanced performance likely resulted from the PhET group's engagement with the simulations, where manipulating variables like solvent volume increased their awareness of the relationships between the variables involved. These results align with studies highlighting the importance of visualization and focused attention when working with digital tools [19].

At the evaluation level, students in the PhET group provided answers that demonstrated a clear understanding of dilution as a method for reducing solute concentration. In contrast, the control group's responses were often shorter and less developed, indicating a more limited grasp of the concept of dilution. Once again, the use of digital simulations helped students visualize the concept more effectively, contributing to a fuller understanding [42].

Finally, in answering the creation question, most students in both groups chose the correct answer, but a significant portion of the control group failed to provide explanations for their choices. This indicates that while both groups could arrive at the correct solution, the PhET simulations helped students articulate their reasoning, further reinforcing the benefits of interactive learning tools in promoting deeper cognitive engagement. The previous issue of explanations provided by the PhET group is of special interest, as this explanation is expected to make understanding sustainable over time. Thus, simulations are required in the science classroom to encourage sustainable students' understanding.

5. Limitations, Conclusions, and Recommendations

The present research investigates the impact of digital simulations on students' understanding. The comparison between the responses to the application questions in both groups underscores the value of using digital tools, such as PhET simulations, at an early stage to enhance students' understanding of scientific concepts. The PhET group's superior performance in applying their knowledge highlights how interactive simulations facilitate deeper comprehension and engagement with the material. This is in line with researchers' findings regarding the contribution of digital simulations to students' learning. Daher and Baya'a [43] found that mobile simulations helped middle school students better understand mathematical concepts by allowing them to explore real-world scenarios both in and out of the classroom. This aligns with previous research suggesting that digital simulations can positively impact students' learning, particularly in the analysis stage. In addition, Daher and Swidan [44] found that simulations helped primary school students better understand relationships among quadrilaterals.

Additionally, the responses to the analysis questions emphasize the significance of understanding the relationship between variables like volume, heat transfer, and solubility. The PhET group demonstrated a stronger grasp of these relationships compared to the control group, suggesting that digital simulations not only improve students' conceptual understanding but also enhance their critical thinking and problem-solving abilities. These findings support the integration of technology-based learning tools in science education to promote more effective and dynamic learning outcomes.

The present study results show that simulation can help elementary school students have better explanations, so these results encourage educational practices that take advantage of digital simulations. They also encourage policymakers to take advantage of digital simulations by incorporating them in the elementary science curriculum.

The authors of the present research are aware of the challenges or limitations of using PhET simulations, such as potential accessibility issues, technical difficulties, or dependency on technology for effective learning. These challenges and limitations require educators and policy makers to plan to overcome them [25,26].

In terms of practical applications, the study highlights the potential of combining digital tools with traditional teaching methods. For optimal outcomes, educators might consider using PhET simulations as a supplement to hands-on activities rather than a replacement. Practical recommendations include beginning with traditional instruction to establish foundational knowledge, followed by simulations to deepen understanding and foster interactive, inquiry-based learning experiences. Furthermore, digital simulations should be customized for specific concepts where visual aids are beneficial for comprehension.

Future research is needed to investigate the influence of digital tools on students' application level. Daher and Sleem [45] found that traditional teaching methods were more effective than 360-degree videos in helping students apply their knowledge. However, the present research suggests that digital simulations can positively impact students' performance and understanding during the application phase. This suggests that digital simulations could be beneficial in supporting student learning in this area. Future research can use the interview as a data collecting tool to examine how students and teachers conceive digital simulations as contributing to students learning, including the application level of knowledge.

The results address the topic of solubility. Future research is needed to investigate the influence of simulations on students' achievement in other topics of science in elementary school, which would add to the generalizability of the present research results. Moreover, factors such as prior knowledge, differences in teaching style, or time spent on tasks, did not influence the results, as these factors were similar in the two research groups. Future research could vary one or more of these factors and observe the results of this variation.

The present research sample could be considered representative of third-grade students who study the relevant topic of chemistry, but future research needs to verify the influence of simulations on students' understanding of chemistry concepts and relations. This future research will enable the applicability of the findings to other educational settings, disciplines, or student populations. Moreover, the observed advantages of the PhET simulations should be examined in relation to their sustainability over time.

In addition to the above, future research could implement interviews with students and teachers regarding the impact of simulation on elementary students' understanding of scientific concepts. This qualitative method can enrich our understanding of the studied educational issue [46].

Author Contributions: Conceptualization, H.D., W.D., N.I., B.R. and A.R.; methodology, H.D., W.D. and N.I.; formal analysis, H.D., W.D. and N.I.; data curation, B.R. and A.R.; writing—original draft preparation, H.D., W.D. and N.I. writing—review and editing, H.D., W.D., N.I., B.R. and A.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Al-Qasemi Academic College of Education (approve number: 12-2023).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data could be provided upon request from the corresponding authors.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Allah Rakha, N. Revolution in Learning Through Digitization: How Technology is Changing the Landscape of Education. *Int. J. Cyber Law* **2023**, *1*.
2. Filippi, S.; Motyl, B. Development of a Tool for Evaluating the Influence of Engineering Students' Perception of Generative AI on University Courses Based on Personality, Perceived Roles in Design Teams, and Course Engagement. *Multimodal Technol. Interact.* **2024**, *8*, 84. [CrossRef]
3. Hallinger, P.; Wang, R. The Evolution of Simulation-Based Learning Across the Disciplines, 1965–2018: A Science Map of the Literature. *Simul. Gaming* **2020**, *51*, 9–32. [CrossRef]
4. Santos KL, B.; Macena, C.S. Teaching chemistry in a playful and experimental way: Proposals for elementary education in public schools. *Seven Ed.* **2024**, *2*, 544–551. [CrossRef]
5. Liarokapis, F.; Milata, V.; Skola, F. Extended Reality Educational System with Virtual Teacher Interaction for Enhanced Learning. *Multimodal Technol. Interact.* **2024**, *8*, 83. [CrossRef]
6. Salhab, R.; Daher, W. The Impact of Mobile Learning on Students' Attitudes towards Learning in an Educational Technology Course. *Multimodal Technol. Interact.* **2023**, *7*, 74. [CrossRef]
7. Elbourhamy, D.M.; Najmi, A.H.; Elfeky, A.M. Students' performance in interactive environments: An intelligent model. *PeerJ Comput. Sci.* **2023**, *9*, e1348. [CrossRef]
8. Talan, T. The effect of simulation technique on academic achievement: A meta-analysis study. *Int. J. Technol. Educ. Sci.* **2021**, *5*, 17–36. [CrossRef]
9. Rayan, B.; Daher, W.; Diab, H.; Issa, N. Integrating PhET Simulations into Elementary Science Education: A Qualitative Analysis. *Educ. Sci.* **2023**, *13*, 884. [CrossRef]
10. Tsai, F.-H.; Hsu, I.Y. Exploring the effects of guidance in a computer detective game for science education. *J. Balt. Sci. Educ.* **2020**, *19*, 647–658. [CrossRef]
11. Agyei, E. Pedagogical Support Structures for Effective Implementation of Simulation-Based Innovation in Science Classrooms: Prospective Teachers' Perspectives. *Afr. J. Educ. Stud. Math. Sci.* **2024**, *20*, 47–74.
12. Otterborn, A.; Sundberg, B.; Schönborn, K. The Impact of Digital and Analog Approaches on a Multidimensional Preschool Science Education. *Res. Sci. Educ.* **2024**, *54*, 185–203. [CrossRef]
13. Salame, I.I.; Samson, D. Examining the Implementation of PhET Simulations into General Chemistry Laboratory. *Int. J. Environ. Sci. Educ.* **2019**, *14*, 207–217.
14. Harvey, D.T.; Le, A.n.-P.; Lucy, C.A.; Mosby, B.M.; Park, E.J. The Use of Simulations with Active Learning Exercises. In *Active Learning in the Analytical Chemistry Curriculum*; American Chemical Society: Washington, DC, USA, 2022; Chapter 8; pp. 121–145. [CrossRef]
15. López-Martínez, A.; Meroño, L.; Cánovas-López, M.; Garcia de Alcaraz, A.; Martínez-Aranda, L. Using Gamified Strategies in Higher Education: Relationship between Intrinsic Motivation and Contextual Variables. *Sustainability* **2022**, *14*, 11014. [CrossRef]
16. Byusa, E.; Kampire, E.; Mwesigye, A.R. Game-based learning approach on students' motivation and understanding of chemistry concepts: A systematic review of literature. *Heliyon* **2022**, *8*, e09541. [CrossRef]
17. Dobal, F.; Lalioti, V. Circular Species: Designing critical thinking into children's science education through biomaterials and augmented reality. In Proceedings of the 20th Annual ACM Interaction Design and Children Conference, Athens, Greece, 24–30 June 2021; pp. 8–17. [CrossRef]
18. Akerson, V.L.; Bartels, S.L. Elementary science teaching: Toward the goal of scientific literacy. In *Handbook of Research on Science Education*; Routledge: London, UK, 2023; pp. 528–558.
19. Evagorou, M.; Erduran, S.; Mäntylä, T. The role of visual representations in scientific practices: From conceptual understanding and knowledge generation to 'seeing' how science works. *Int. J. STEM Educ.* **2015**, *2*, 11. [CrossRef]
20. Jere, S.; Mpeta, M. Enhancing Learners' Conceptual Understanding of Reaction Kinetics Using Computer Simulations—A Case Study Approach. *Res. Sci. Educ.* **2024**, *54*, 999–1023. [CrossRef]

21. Jammeh, A.L.J.; Karegeya, C.; Ladage, S. Application of technological pedagogical content knowledge in smart classrooms: Views and its effect on students' performance in chemistry. *Educ. Inf. Technol.* **2024**, *29*, 9189–9219. [CrossRef]
22. Kalogiannakis, M.; Papadakis, S.; Zourmpakis, A.-I. Gamification in Science Education. A Systematic Review of the Literature. *Educ. Sci.* **2021**, *11*, 22. [CrossRef]
23. Kolil, V.K.; Achuthan, K. Virtual labs in chemistry education: A novel approach for increasing student's laboratory educational consciousness and skills. *Educ. Inf. Technol.* **2024**. [CrossRef]
24. Pavlo, P.; Serhiy, O.; Olesia, Y. Cloud technologies of augmented reality as a means of supporting educational and research activities in chemistry for 11th grade students. *Educ. Technol. Q.* **2023**, *2023*, 69–91. [CrossRef]
25. McGuire, S.; Shawn, M. Educational Inequities: Impact of Technology and Internet Access on Online Learning in Title I Schools. Ph.D. Thesis, Sanford College of Education, National University, San Diego, CA, USA, 2024.
26. West, M. *An Ed-Tech Tragedy? Educational Technologies and School Closures in the Time of COVID-19*; UNESCO Publishing: Paris, France, 2023.
27. Hillmayr, D.; Ziernwald, L.; Reinhold, F.; Hofer, S.I.; Reiss, K.M. The potential of digital tools in secondary science learning. *Comput. Educ.* **2020**, *153*, 103897. [CrossRef]
28. Bahtiar, B.; Ibrahim, I. Analysis of Students' Scientific Literacy Skills. *J. Pendidik. IPA Indones.* **2022**, *11*, 371–386.
29. Mashami, R.A.; Ahmadi; Kurniasih, Y.; Khery, Y. Use of PhET Simulations as A Virtual Laboratory to Improve Students' Problem Solving Skills. *J. Penelit. Pendidik. IPA* **2023**, *9*, 11455–11465. [CrossRef]
30. Astuti, T.N.; Sugiyarto, K.H.; Ikhsan, J. Effect of 3D Visualization on Students' Critical Thinking Skills and Scientific Attitude in Chemistry. *Int. J. Instr.* **2020**, *13*, 151–164. [CrossRef]
31. Salame, I.I.; Makki, J. Examining PhET's impact on attitudes and learning in chemistry. *Interdiscip. J. Environ. Sci. Educ.* **2021**, *17*, e2247. [CrossRef]
32. Schwarz, C.V.; White, B.Y. Metamodeling Knowledge: Developing Students' Understanding of Scientific Modeling. *Cogn. Instr.* **2005**, *23*, 165–205. [CrossRef]
33. Anderson, L.W.; Krathwohl, D.R. (Eds.) *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*; Allyn & Bacon: Boston, MA, USA, 2001.
34. Krathwohl, D.R. A Revision of Bloom's Taxonomy: An Overview. *Theory Into Pract.* **2002**, *41*, 212–218. [CrossRef]
35. Zorluoğlu, S.L.; Gün, N. Investigation of the Science Individualized Education Programs' Learning Outcomes According to the Revised Bloom Taxonomy. *J. Educ. Futur.* **2024**, 67–80. [CrossRef]
36. Pavlou, Y.; Zacharia, Z.C. Using Physical and Virtual Labs for Experimentation in STEM+ Education: From Theory and Research to Practice. *Shap. Future Biol. Educ. Res.* **2024**, *1*, 3–19.
37. Banda, H.J.; Nzabahimana, J. Effect of integrating physics education technology simulations on students' conceptual understanding in physics: A review of literature. *Phys. Rev. Phys. Educ. Res.* **2021**, *17*, 023108. [CrossRef]
38. Krüger, J.T.; Höffler, T.N.; Wahl, M.; Knickmeier, K.; Parchmann, I. Two comparative studies of computer simulations and experiments as learning tools in school and out-of-school education. *Instr. Sci.* **2022**, *50*, 169–197. [CrossRef]
39. Rianti, R.; Gunawan, G.; Verawati, N.N.S.P.; Taufik, M. The Effect of Problem Based Learning Model Assisted by PhET Simulation on Understanding Physics Concepts. *Lensa J. Kependidikan Fis.* **2024**, *12*, 28–43. [CrossRef]
40. Simanjuntak, M.P.; Hutahaean, J.; Marpaung, N.; Ramadhani, D. Effectiveness of Problem-Based Learning Combined with Computer Simulation on Students' Problem-Solving and Creative Thinking Skills. *Int. J. Instr.* **2021**, *14*, 519–534. [CrossRef]
41. Taibu, R.; Mataka, L.; Shekoyan, V. Using PhET simulations to improve scientific skills and attitudes of community college students. *Int. J. Educ. Math. Sci. Technol. (IJEMST)* **2021**, *9*, 353–370. [CrossRef]
42. Daher, W.M. Grade 10 students' technology-based exploration processes of narratives associated with the sine function. *EURASIA J. Math. Sci. Technol. Educ.* **2020**, *16*, em1852. [CrossRef]
43. Daher, W.; Baya'a, N. Characteristics of middle school students learning actions in outdoor mathematical activities with the cellular phone. *Teach. Math. Its Appl. Int. J. IMA* **2012**, *31*, 133–152. [CrossRef]
44. Daher, W.; Swidan, O. Positioning–Emotions Association of Young Students Using Digital Technology. *Mathematics* **2021**, *9*, 1617. [CrossRef]
45. Daher, W.; Sleem, H. Middle school students' learning of social studies in the video and 360-degree videos contexts. *IEEE Access* **2021**, *9*, 78774–78783. [CrossRef]
46. Daher, W. Schools' Challenges in Distance Learning during Emergency Education: Focus Group Methodology. *Educ. Sci.* **2024**, *14*, 383. [CrossRef]