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The effect of virtual laboratory applications on the achievement of secondary school students in learning the granular structure of matter

Esra Özeler [1] , Yaşar Genel [2] , Salih Genel [3*]

[1] Van Yuzuncu Yil University, Faculty of Education, Van, Türkiye
[2] Van Yuzuncu Yil University, Faculty of Education, Van, Türkiye
[3] Van Yuzuncu Yil University, Faculty of Education, Van, Türkiye

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*Corresponding Author:
Salih Genel
E-mail: sgenel@yyu.edu.tr

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Abstract

Purpose: The objective of this study is to investigate the impact of virtual laboratory applications on students' performance in the teaching of the subject matter "Particulate Structure of Matter" to middle school students.

Design and Methodology: The study was conducted in two public educational establishments. The study sample comprised 191 seventh-grade students. The study employed a quasi-experimental design, utilising a pre-test-post-test control group. The study employed an achievement test as the primary data collection instrument. The subject of "Particulate Structure of Matter" was taught using the methods prescribed by the current curriculum for the control group and a computer-aided virtual laboratory application for the experimental group. The data were subjected to quantitative analysis using the SPSS data analysis program, and the results were obtained. Independent groups t-test analyses were conducted to examine the differences between the means in the data obtained from the experimental and control groups.

Results: The findings revealed that the results were statistically significant at $p<0.05$. Consequently, it was concluded that there was a significant difference in favour of the experimental group and that virtual laboratory applications were more effective in teaching the subject of particulate structure of matter to middle school students.

Implications & Suggestions: A comparative analysis of the implementation and impact of virtual laboratory applications can be conducted by examining the differences between interactive and non-interactive applications.

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1. INTRODUCTION

One of the topics addressed in science courses at the middle school level is the particulate structure of matter. The subject enables an understanding of the formation of matter, its properties, its transitions between states, the distinction between heat and temperature, the concept of density, the preparation of mixtures and the processes involved in their separation. The particulate structure of matter occupies a significant position in the curriculum of science courses, as it is also pertinent to other scientific disciplines. In Turkey, students commence their study of the "Particulate Structure of Matter" subject in the sixth grade (MEB, 2018). The accurate acquisition of these subjects and concepts serves as a foundation for the subsequent learning of numerous high school chemistry concepts (Adadan, 2013).

As students are unable to perceive the particles of matter with their eyes, they experience difficulty in forming an image or concept of them. This situation presents a challenge for students in learning the concepts of the particulate structure of matter (Ayas et al., 2002; Özmen, 2004). The research conducted by Altay and Balım (2021) focused on an examination of 17 studies conducted between 2002 and 2020 on the subject of "Particulate Structure of Matter". It was found that the majority of the studies examined aimed to determine the prevalence of misconceptions and that there were common misconceptions among students.

In order to surmount these challenges, it is vital to equip students with activities that will facilitate the concretisation, visualisation and simulation of the particulate structure of matter and other scientific disciplines. In the literature, there are studies examining the teaching of more abstract concepts and subjects in science courses. These include the use of animation (Daşdemir, 2016), laboratory practice courses (İlhan et al., 2009), virtual laboratories (Udin et al., 2020), and computer-assisted teaching (Gökulu, 2013; İlyasoğlu & Aydın, 2014; Karaçöp, 2012; Karaduman & Emrahoğlu, 2011; Renshaw & Taylor, 2000).

Experimentation and laboratory work occupy a significant position in the learning and teaching of scientific subjects. Virtual laboratory courses have a variety of applications, including those related to virtual reality, augmented reality, animation, and simulation. The use of virtual laboratories has been demonstrated to enhance student motivation through the provision of visuals and interaction (Estriegana et al., 2019; Guzman et al., 2021). The utilisation of laboratories and experimentation facilitate students' acquisition of scientific concepts (Bozkurt & Sarıkoç, 2008; Ramirez et al., 2020). Conversely, in recent years, virtual laboratories have begun to be utilised in virtual environments, in addition to face-to-face environments, where students can utilise and experiment. This has also been the subject of numerous scientific studies in this field (Udin et al., 2020).

The utilisation of virtual laboratory applications presents a favourable avenue for students to cultivate positive attitudes towards science courses, particularly in relation to their learning success and effectiveness in these courses (Baş, 2022). In the study conducted by Duman and Avcı (2016), the impact of virtual laboratory applications on the identification and eradication of misconceptions encountered in the "States of Matter and Heat" unit was investigated. The study demonstrated that virtual laboratory applications were an effective tool for student success and the retention of knowledge in a teacher-centred learning environment. The findings align with those of Harrison and Treagust (2000), who asserted that the utilisation of visual teaching materials, including visual models, demonstrations, animations and simulations, facilitated the construction of models in students' minds, a process that was observed in the context of textbook-based learning.

Virtual laboratories facilitate interactive learning for a variety of subjects and lessons through the use of animations and simulations (Bozkurt & Sarıkoç, 2008). There are numerous similarities and differences between laboratory applications conducted in actual, physical, face-to-face settings and those performed in virtual laboratories. The utilisation of virtual laboratory applications may present a multitude of advantages and disadvantages for students. Virtual laboratories afford students the opportunity to engage in experiments in a manner that is centred on their individual needs and preferences. Furthermore, students can undertake these experiments repeatedly, and they can also access learning opportunities that are independent of time and place. The EBA education platform was established by the Ministry of National Education (MEB), and the utilisation of animations, simulations and virtual laboratories in educational and training processes has increased further. PhET (http://www.phet.colorado.edu) applications, which provide a plethora of interactive content in online environments as virtual laboratories in science education, are employed by both teachers and numerous researchers (İlyasoğlu & Aydın, 2014).

It is acknowledged that there is a direct correlation between the utilisation of interactive virtual laboratory applications, such as PhET, in the field of science education and the integration of artificial intelligence. The advent of artificial intelligence has led to a proliferation of machines and software that exhibit human-like cognitive abilities within virtual environments. The utilisation of artificial intelligence is becoming increasingly prevalent in the field of science education (Jia et al., 2023). Kiraz (2014) carried out his study on artificial intelligence-supported virtual laboratory design. A review of the literature on the teaching of the subject of "Particulate Structure of Matter" reveals a preponderance of studies on virtual laboratories that incorporate animations without user interaction (Danacı, 2018; Daşdemir, 2016; Okumuş et al., 2016). The present study concerns the development of interactive virtual laboratory applications on the subject of "Particulate Structure of Matter." It is proposed that this study will make a significant contribution to the field by examining the impact of such applications.

The subject of the science course, "Particulate Structure of Matter," presents a significant challenge for traditional laboratory-based instruction due to its abstract nature, microscopic scale, and the dynamic interactions between particles within molecular structures. The issue that this study seeks to address is the necessity for investigating student success in virtual laboratory environments, as opposed to traditional laboratory approaches.

The objective of this study is to investigate the impact of virtual laboratory applications on student performance in the teaching of the subject matter of "Particulate Structure of Matter" to middle school students. The research problem can be stated as follows:

Is there a significant difference in favor or against the course success of the students in the experimental group where virtual laboratory application was used and the control group students in the subject of “Particulate Structure of Matter” in the seventh grade middle school science course?

2. METHOD

2.1. Research Design

This study was conducted in accordance with the standards of quantitative research and with a quasi-experimental research design. In the course of the research, the impact of traditional teaching and virtual laboratory applications conducted in accordance with the prevailing curriculum were contrasted and evaluated in terms of students' performance in the subject of "Particulate Structure of Matter". Quasi-experimental research designs are employed to investigate the impact of pedagogical approaches in the context of educational research. As the experimental group received instruction through the virtual laboratory method, while the control group followed the established curriculum, the study employed a pre-test-post-test design with a control group comprising both experimental and control groups (Fraenkel & Wallen, 2011; McMillan & Schumacher, 2006). Prior to the commencement of the research, ethical approval was sought and obtained from the university ethics committee. Furthermore, the requisite official permissions were obtained from the national education directorates for the secondary school, which is a state school, where the study would be conducted. Table 1 presents an overview of the research design, which compares the use of virtual laboratories and traditional methods in the context of the current curriculum.

Table 1. *Research Design Application*

Groups	Pretest	Application	Posttest
Experimental	Achievement Test (Particular Structure of Matter)	Virtual Laboratory Application	Achievement test (Particle Structure of Matter)
Control	Achievement test (Particle Structure of Matter)	Traditional Education According to the Current Program	Achievement test (Particle Structure of Matter)

2.2. Sample of the Study

The study sample comprises 191 seventh-grade students from two middle schools (A1 and A2) in a district of a province in the eastern region of Türkiye, selected during the 2023-2024 academic year. The seventh grade is divided into four branches at both schools. Two of these branches were randomly selected as the experimental group, while the remaining two were selected as the control group.

In determining the sample and selecting the schools in which the study will be conducted, factors that may affect the success of the students were taken into consideration, and care was taken to ensure that schools with similar characteristics were selected. Furthermore, additional criteria were considered, including similarity in socio-economic and cultural aspects, comparable student knowledge levels, both schools being public institutions, and the researcher's prior experience working in these schools. The same instructor teaches both the experimental and control groups in the two schools where the study is conducted.

The data set comprises the number of students in the experimental and control groups, the number and detailed information in terms of both the experimental and control groups and the schools and classes, as presented in Table 2.

Table 2. *A Numerical Distribution of the Experimental and Control Groups*

School Type	Number of Students	Number of CG Students	Number of EG Students
Public School (A1)	95	48	47
Public School (A2)	96	50	46
Total	191	98	93

2.3. Teaching practices

In order to carry out the applications in the study, the subject of "F.7.4.1 Particulate Structure of Matter" from the "Pure Substances and Mixtures" unit of the seventh grade Science Course was selected. The subject was restricted to four learning outcomes in accordance with the middle school level. The course content was developed in alignment with the specified learning outcomes. The experimental and control groups were engaged in the study for a total of six lesson hours. The achievement test, which was employed as a pretest and posttest in the study, was also developed in accordance with the aforementioned learning outcomes. A comprehensive overview of the subject, including its constituent sub-areas, learning outcomes, recommended teaching times, key concepts and explanations, is provided in Table 3. Despite the existence of analogous learning outcomes and concepts in the experimental and control groups, distinct lesson plans were devised for each. The achievement test for the particulate structure of matter was conducted in accordance with the learning outcomes as set out in the current study.

Table 3. *Framework for the Particulate Structure of Matter*

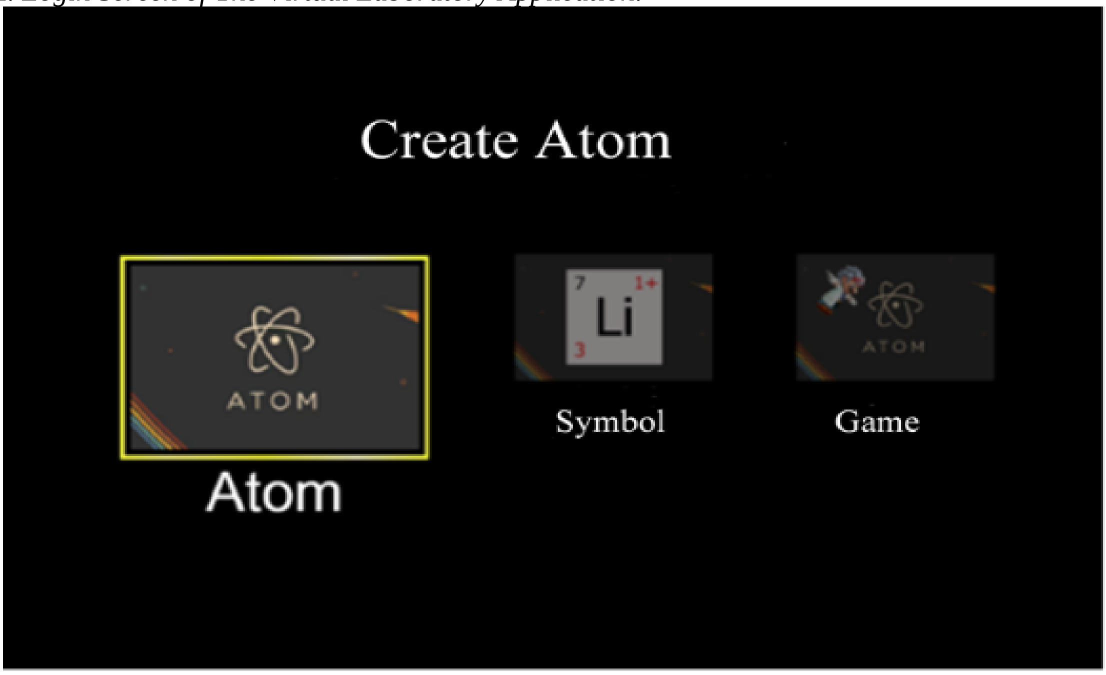
Section	Learning outcomes	Time for lesson	concepts	Explanation
Structure of the Atom	F.7.4.1.1. It tells the structure of the atom and the fundamental particles in its structure.	2	Atom (nucleus, layer, proton, neutron, electron), property of scientific knowledge, molecule	Details about atomic theories are not given.
Atomic Models	F.7.4.1.2. Questions how ideas about the concept of atom have changed from past to present.	2		It is emphasized that scientific knowledge may change over time.
Molecule	F.7.4.1.3. It indicates that the same or different atoms will come together to form a molecule. F.7.4.1.4. It creates and presents various molecule models.	2		General information about theory, one of the types of scientific knowledge, is given.

The implementation of the applications was conducted in accordance with the instructions set forth in the textbooks utilized by the Ministry of National Education, in alignment with the prevailing curriculum. The control group received instruction within the aforementioned framework, as delineated in Table 3. To ensure uniformity in the application of the lessons, the teachers were provided with analogous lesson plans and presentations, enabling them to impart the material in a consistent manner.

2.4. Use of Virtual Laboratory for Experimental Group

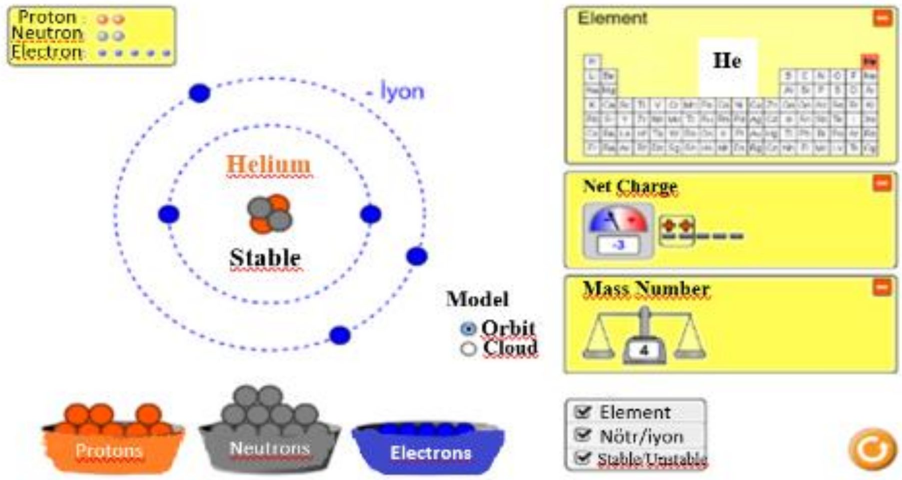
In order to facilitate the processing of the lessons in the experimental group, computer-aided virtual laboratory applications were implemented in lieu of the activities outlined in the textbook, in alignment with the current curriculum's prescribed achievements and concepts. In the experimental group, the computer-aided virtual laboratory applications were based on the open source "Build in Atoms" application, the source code of which is accessible to chemistry teachers. This application was translated into Turkish with the support of experts and accompanied by visual aids. The source code can be accessed via the following link: https://phet.colorado.edu/sims/html/build-an-atom/latest/build-an-atom_en.html.
The user interface is designed for ease of use by educators and students alike. The virtual laboratory application comprises three modules, the visuals of which are displayed in Figure 1.

Figure 1. *Login Screen of The Virtual Laboratory Application.*



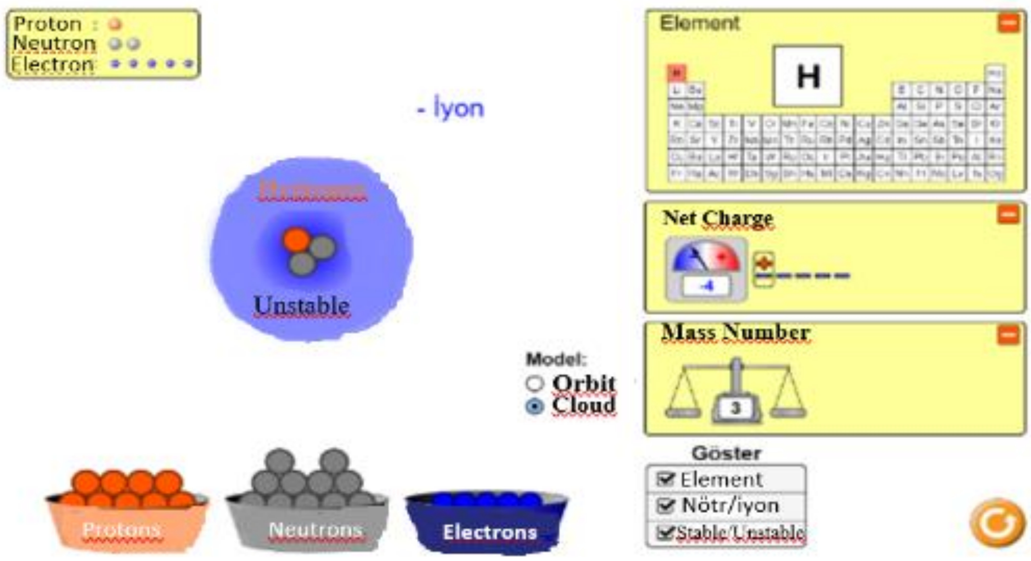
The user is able to place the protons, neutrons and electrons, which are the fundamental particles of the atom, in the atom module according to their relevant layers. Should the user attempt to place them in an incorrect layer, a warning is generated as the layer is not valid and the particle cannot be placed there. The number of particles placed allows the user to ascertain the element, mass number and ion charge. The first ten most common elements can be worked on this screen. The position of these first ten elements in the periodic table according to the number of protons placed in the nucleus is also displayed as an additional feature. The application image showing these features is also shown in Figure 2.

Figure 2. *Atom Generation Module Screenshot.*



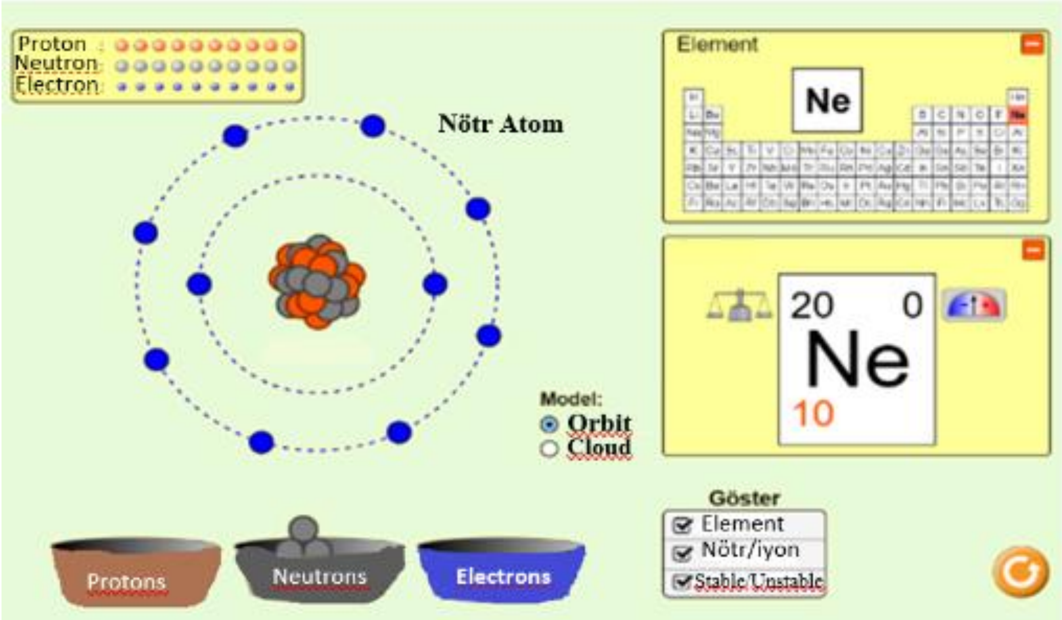
Moreover, the number of protons and neutrons placed in the nucleus determines whether the atom is stable or unstable. These properties can also be observed in motion in the cloud structure. The screenshot illustrating this phenomenon is also shown in Figure 3.

Figure 3: *A Cloud Screenshot of the Stable and Unstable Structure of the Atom.*



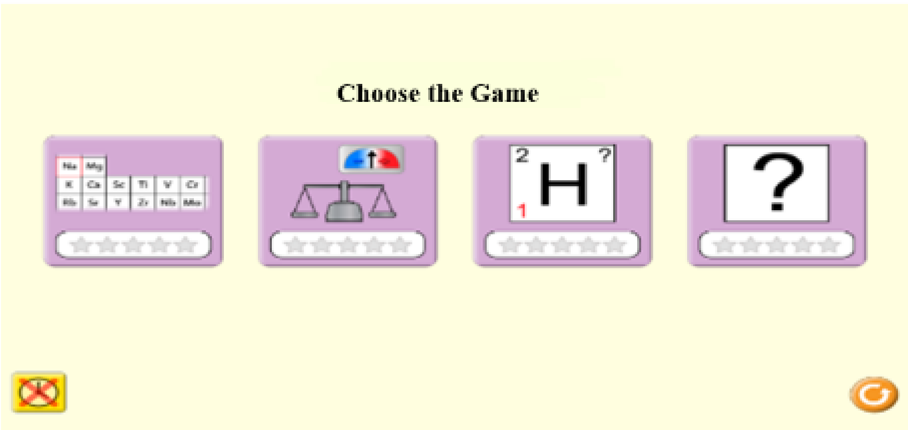
The symbol module allows the user to observe how the symbol of the element, along with the mass number, ion charge and proton number, are displayed in accordance with the numerical status of the particles situated within the core and layers. The screenshot of the symbol module is presented in Figure 4.

Figure 4: *A screenshot of the symbol module.*



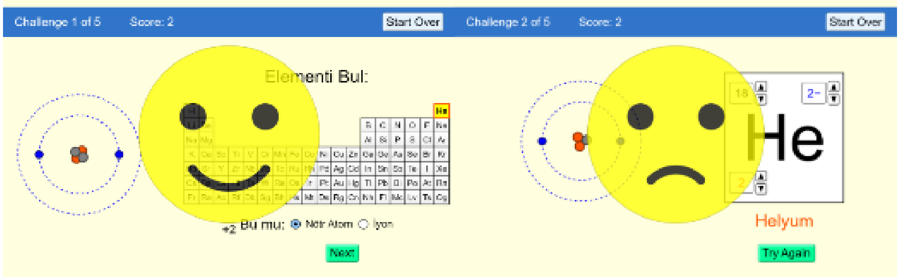
The responses to the queries may be set to a timed or indefinite duration. The user may receive auditory and visual feedback on the correct answers they have provided. The screenshot of this module is presented in Figure 5.

Figure 5. *Screenshot of the virtual laboratory question-and-answer module.*



Furthermore, upon completion of the responses, the outcome can be ascertained. Each question and answer section encompasses a multitude of elements, including the identification of its position in the periodic table based on the specified atomic structure, the generation of symbols, the calculation of ion charge and mass number. Additionally, screenshots illustrating the results of random, correct and incorrect answers in this module are presented in Figure 6.

Figure 6. *Screenshots of Virtual Laboratory Questions and Answers.*



2.5. Data Collection Tool

In this study, the Achievement Test was employed to ascertain the learning levels of students with regard to the subject of Particulate Structure of Matter. The achievement test, which assesses students' knowledge of the subject matter "Particulate Structure of Matter," was developed as part of the research project. The results presented in Table 3 were taken into account during the construction of the test. In the initial stages of the test's development, the researchers constructed an item pool comprising 30 questions. The preparation and development of the questions were conducted by three science teachers and an associate professor of chemistry. The suitability of these questions for the subject of "Particulate Structure of Matter" at the secondary school level was evaluated. In the development of the achievement test, similar processes were employed, with an examination of the literature to gather evidence for reliability and validity (İlhan & Hoşgören, 2017). Following the administration of the test, various corrections were made to the questions. These were based on the opinions of experts on a number of issues, including the suitability of the questions for the stated objectives, their shape and appearance, the clarity of the question wording, and the formats of the questions. The aim was to ensure that the test had the desired scope and face validity.

The following section presents a selection of questions from the examination in order to illustrate the format and content of the assessment.

Question 2: Which of the following statements about the atom is inaccurate?
A) Protons and neutrons are located within the nucleus of the atom.
B) Electrons exhibit rapid movement around the nucleus.
C) The particle that defines the identity of the atom is the electron.
D) Neutrons are uncharged particles.
Question 4: Which of the following are the fundamental particles that constitute the atom?
A) Neutron, Proton, Cation
B) Proton, Neutron, Nucleus
C) Nucleus, Electron
D) Proton, Neutron, Electron
Question 6: Which particle is found in the nucleus of the atom?
A) Electron
B) Proton
C) Cation
D) Nucleus

The 30-question test, which provided content and face validity in line with expert opinions, was administered to 157 eighth-grade students who had previously studied the particulate structure of matter in two state middle schools. The responses to the 30-item test were scored as follows: correct answers were awarded a score of 1, while incorrect or omitted responses were assigned a score of 0. Based on the total scores obtained from the test, the 42 students with the highest scores were identified as the upper group, and the 42 students with the lowest scores were designated as the lower group. In order to select the most appropriate items for the test, item analyses, item difficulty index, item discrimination index, item correlation analyses and Kuder-Richardson–20 (KR-20) reliability coefficient were calculated, taking the aforementioned scores into consideration. The item difficulty index provides a measure of the proportion of students who answer the questions in the test correctly (expressed as a value between "0" and "1"). If this value is close to one, it can be interpreted as indicating that the question is relatively straightforward; conversely, if it is close to zero, it can be interpreted as indicating that the question is more challenging. The item discrimination index examines an item in terms of its capacity to distinguish between students in the lowest and highest 27% percentiles in terms of their total score.For each item on the test, item difficulty indexes and item discrimination indexes were calculated according to the subgroup-upper group method (Table 4). Based on these analyses, it was determined that items 8, 15, and 23 should be removed from the test.

Table 4. *Item Difficulty and Discrimination Indexes*

Question Number	Item Difficulty Index	Item Discrimination Index	Question Number	Item Difficulty Index	Item Discrimination Index
1	0.65	0.45	16	0.54	0.31
2	0.70	0.21	17	0.68	0.21
3	0.61	0.50	18	0.56	0.64
4	0.57	0.57	19	0.37	0.45
5	0.58	0.64	20	0.54	0.50
6	0.64	0.52	21	0.64	0.67
7	0.83	0.33	22	0.54	0.69
8*	**0.73***	**0.12***	23*	**0.51***	**-0.55***
9	0.56	0.31	24	0.50	0.67
10	0.63	0.45	25	0.37	0.45
11	0.58	0.74	26	0.54	0.50
12	0.75	0.50	27	0.67	0.62
13	0.71	0.33	28	0.54	0.69
14	0.68	0.36	29	0.58	0.55
15*	**0.87***	**0.17***	30	0.50	0.67
			Avg. Index	**0.61**	**0.44**

Following the removal of these questions, the average difficulty index of the test was recalculated as 0.54, while the average item discrimination index was recalculated as 0.45. This provided the determined confidence interval. In order to ensure the selection of suitable items for the achievement test, an item-total correlation analysis was conducted. Correlation analysis is employed to ascertain the relationship between the total score obtained from each question and the total score obtained from the test, thereby elucidating the relationship. It is emphasised in the literature that items with a question-total correlation value exceeding 0.30 should be included in the test (İlhan & Hoşgören, 2017; Ferketich, 1991).

A correlation analysis was conducted to ascertain the relationship between the question scores and the total scores. This analysis led to the conclusion that questions 2, 16, and 17 should be removed from the test (Table 5).

Table 5. *Item-Total Correlations of the Items in the Test*

Question Number	Item-Total Correlation Value	Question Number	Item-Total Correlation Value
1	0.378	17*	**0.188***
2*	**0.201***	18	0.496
3	0.432	19	0.472
4	0.439	20	0.426
5	0.464	21	0.557
6	0.405	22	0.543
7	0.339	24	0.598
9	0.308	25	0.472
10	0.339	26	0.426
11	0.549	27	0.537
12	0.462	28	0.543
13	0.318	29	0.362
14	0.338	30	0.598
16*	**0.282***		

Following the completion of the item analyses, six questions that did not meet the requisite values as a result of the analyses were removed from the 30-question test, leaving a 24-question test that was deemed suitable for further analysis. The KR-20 reliability coefficient of this 24-question test was calculated as 0.83, indicating that the test is highly reliable.

2.5. Analysis of Data

In the study, the achievement test on the subject of "Particulate Structure of Matter" was administered to both the experimental and control groups as both a pretest and a posttest. The data obtained from the achievement test were analysed using the SPSS (Statistical Package for the Social Sciences) program. Each question was evaluated as 1 point for the correct answer and 0 points for the wrong answer, and used in the scoring in this way. The data were then examined descriptively. The study employed the independent sample t-test to ascertain whether there were significant differences between the means of the groups. In order to conduct an independent group t-test, it is essential that the selected groups are independent of one another and that the data follows a normal distribution (Büyüköztürk, 2010; Can, 2019). The normality of the data distribution was evaluated by examining the descriptive statistical values, kurtosis, and skewness. The observed values of kurtosis and skewness fell within the range of +1 to -1, indicating that the data did not deviate significantly from the normal distribution. The findings section presents the results of this analysis.

3. RESULTS / FINDINGS

3.1. Pre-Test Values of Experimental and Control Groups

The data collected as a pre-test and post-test with the "Particulate Structure of Matter" achievement test were subjected to analysis. Table 6 presents the distribution of students in the study according to the experimental and control groups prior to the implementation of the intervention, along with the average score values of the groups. It can be observed that the average pre-test score of the 98 students in the control group was 11.8776, while the average pre-test score of the 93 students in the experimental group was 11.8387.
Table 6 presents the descriptive statistical analysis values (median, variance, minimum, maximum scores, kurtosis and skewness values, etc.) of the pre-test scores of the experimental and control group students. An examination of the kurtosis and skewness values indicates that the data also meet the normality assumption.

Table 6. *Descriptive Values of Pre-Test Scores of Experimental and Control Groups*

Descriptive values	Control Group	Experimental Group
Number of Students	98	93
Minimum Score	2	2
Maximum Score	24	24
Average Score	11.88	11.84
Standard Deviation	5.591	5.029
Skewness	.499	.271
Kurtosis	-.854	-.651

In order to ascertain whether there was a statistically significant difference between the group means in terms of the achievement test, an independent groups t-test was conducted. The results of this analysis, which compared the mean scores obtained from the students according to group type, are presented in Table 7. A comparison of the pretest results reveals no statistically significant difference between the experimental and control groups in terms of their achievement test scores ($t(189) = .050$; $p > .05$). Consequently, the achievement status of the students in the experimental and control groups on the subject of "Particulate Structure of Matter" is found to be similar.

Table 7. *Pre-Test Scores of Groups Independent Groups T-Test Analysis*

Group	N	M	Sd	Df	t	p
Control	98	11.88	5.591	189	0.050	.960
Experimental	93	11.84	5.029			

N: Number of Students, M: Average Score, Standard Deviation (sd), Df: Degree of Freedom, p: Significance level

3.1. Post-Test Values of the Experimental and Control Group

In the study, the "Particulate Structure of Matter" achievement test was administered to the experimental and control groups as a posttest following the virtual laboratory applications. The data were analysed using both descriptive and independent groups t-tests. Table 8 presents the distribution of students in the study according to experimental and control groups, as well as the average score values of these groups. It can be observed that the average posttest score of students in the control group on the subject of "Particulate Structure of Matter" is 13.84, while the average posttest score of students in the experimental group is 16.54.

Table 8 presents the descriptive values (median, variance, minimum, maximum scores, kurtosis and skewness values, etc.) of the scores obtained by the experimental and control group students from the final application of the tests on the subject of "Particulate Structure of Matter". Upon examination of the kurtosis and skewness values, it can be concluded that the data meet the normality assumption.

Table 8. *Post-Test Scores of Groups Independent Groups T-Test Analysis*

Descriptive values	Control Group	Experimental Group
Number of Students	98	93
Minimum Score	2	10
Maximum Score	24	24
Average Score	13.84	16.54
Standard Deviation	4.886	3.105
Skewness	.404	.206
Kurtosis	-.557	-.679

When the independent groups t-test analysis results (Table 9) are examined, a significant difference was found between the achievement test average of the students in the experimental group where the virtual laboratory was used and the achievement test average of the students in the control group in favor of the experimental group, t(189)=4.583; p<0.05. Therefore, when the pre-test data are considered, it can be said that the virtual laboratory applications have an effect on increasing the students' success.

In order to ascertain whether the discrepancy between the scores attained in the post-tests on the subject of "Particulate Structure of Matter" is statistically significant, the results of the independent groups t-test analysis are presented in Table 9.

Table 9. *Independent Groups T-Test Analysis Results Applied to Post-Test Results According to Group Type*

Group	N	M	SS	Df	t	p
Control	98	13.84	4.886	189	-4.532	.00
Experimental	93	16.54	3.105			

P<.05

4. DISCUSSION and CONCLUSION

The present study examined the impact of virtual laboratory applications on the teaching of particulate structure of matter in 7th grade in middle school, with a particular focus on student success. The present study revealed that there was no statistically significant difference between the pre-tests administered to the experimental and control groups in the selected schools prior to the implementation of virtual laboratory applications. However, following the implementation of the applications, a significant difference emerged in favour of the experimental group with regard to the success status of the students in the experimental and control groups on the subject of "Particulate Structure of Matter". A comparison of the pre-test and post-test results indicates that virtual laboratory applications had a positive impact on students' success in the subject of "Particulate Structure of Matter" in 7th grade. In the present study, activities from the PhET platform (http://www.phet.colorado.edu) were employed as virtual laboratory applications. It can be posited that the PhET activities played a pivotal role in enhancing students' success. The study yielded significant findings pertaining to the identification of methodologies that facilitate students' success in the subject of "Particulate Structure of Matter".

A review of the literature reveals numerous studies conducted in Türkiye that demonstrate the efficacy of virtual laboratory applications in enhancing academic performance in various subjects, including physics, chemistry, and biology, within the context of science education. These studies have consistently shown that virtual laboratory applications lead to higher levels of academic success compared to traditional methods (Çinici et al., 2013; Duman & Avcı, 2016; Özdener, 2005; Yılmaz & Eren, 2014). Conversely, international studies yield comparable findings regarding the impact of virtual laboratories on academic performance (Banda & Nzabahimana, 2022; Ganasen & Shamuganathan, 2017; Smetana & Bell, 2012).
In some studies on the impact of virtual laboratory applications on students' academic performance in science education, similar outcomes have been observed in comparison groups (Aydın, 2018). Rutten et al. (2012) investigated the potential for enhancing traditional science education through the integration of computer simulations. Their findings underscored the significance of student engagement, the manner in which information obtained through simulations is presented and processed, and the role of well-designed simulation-based education in achieving optimal outcomes.

Suggestion

In the implementation of virtual laboratory applications, it can be realised as either animation or simulation in the field of writing. The current study demonstrates that PhED applications are designed more as simulations. In different studies, artificial intelligence tools can be developed and applications can be made for virtual laboratory applications. A comparative analysis of the implementation and impact of virtual laboratory applications can be conducted by examining the differences between interactive and non-interactive applications. In this study, the focus is on the "Particulate Matter Subject." By extending this analysis to other subjects, we can contribute to the advancement of this field.

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The authors declare no conflict of interest. This research study complies with research publishing ethics. The scientific and legal responsibility for manuscripts published in IJEDAI belongs to the author(s).

Authorship Contribution Statement

Author Esra Özeler: Investigation, Resources, Software, Analysis, Author Yaşar GENEL: : Supervision , Methodology, Software, Analysis, Author Salih GENEL: Analysis, Wrote the article and Validation.

REFERENCES

Adadan, E. (2013). Using multiple representations to promote grade 11 students' scientific understanding of the particle theory of matter. *Research in Science Education, 43*, 1079-1105.

Altay, E. & Balım, A. G. (2021). Maddenin tanecikli yapısı ile ilgili kavram yanılgılarının tespiti. *Batı Anadolu Eğitim Bilimleri Dergisi, 12*(2), 576-592.

Ayas, A. Özmen, H. & Coştu, B. (2002). Maddenin tanecikli yapısının öğretiminde karşılaşılan zorluklar. Eğitim ve Bilim, 27(158), 79-88.

Aydın, Ş. Z. N. (2018). Fen bilgisi dersi öğretiminde sanal laboratuvar uygulamasının kullanılması ve değerlendirilmesi. İstanbul Üniversitesi: Yüksek lisans tezi.

Baş, K. (2022). Fen eğitiminde sanal laboratuvar uygulamalarının öğrencilerin akademik başarılarına ve fen tutumlarına etkisi. Akdeniz Üniversitesi: Yüksek lisans tezi.

Banda, H. J., & Nzabahimana, J. (2023). The impact of physics education technology (PhET) interactive simulation-based learning on motivation and academic achievement among. *Malawian physics students. Journal of Science Education and Technology*, *32*(1), 127–141. https://doi.org/10.1007/s10956-022-10010-3

Bozkurt, E., & Sarıkoç, A. (2008). Fizik Eğitiminde Sanal Laboratuvar, Geleneksel Laboratuvarın Yerini Tutabilir mi?. *Selçuk Üniversitesi Ahmet Keleşoğlu Eğitim Fakültesi Dergisi, 25,* 89-100.

Büyüköztürk, Ş. (2010). Sosyal bilimler için veri analizi el kitabı [Handbook of data analysis for social sciences]. Pegem Akademi.

Can, A. (2019). SPSS ile bilimsel araştırma sürecinde nicel veri analizi. 7. Baskı, Pegem Akademi, Ankara.

Çinici, A., Özden, M., Akgün, A., Ekici, M., & Yalçın, H. (2013). Sanal ve gerçek laboratuvar uygulamalarının 5. sınıf öğrencilerinin ışık ve ses ünitesiyle ilgili başarıları üzerine etkisinin karşılaştırılması. *Bayburt Eğitim Fakültesi Dergisi, 8*(2), 92-106.

Danacı, F. (2018) Maddenin tanecikli yapısının animasyonla öğretiminin öğrencilerin akademik başarıları üzerindeki etkisi. Van Yüzüncü Yıl Üniversitesi: Yüksek lisans tezi.

Daşdemir, İ. (2016). Animasyon kullanımının öğrencilerin akademik başarılarına, öğrenilen bilgilerin kalıcılığına ve bilimsel süreç becerilerine etkisi. Kastamonu Eğitim Dergisi, 21(4), 1287-1304.

Duman, M. Ş. & Avcı, G. (2016). Sanal laboratuvar uygulamalarının öğrenci başarısına ve öğrenilenlerin kalıcılığına etkisi. *Erzincan Üniversitesi Eğitim Fakültesi Dergisi, 18*(1), 13-33. https://doi.org/10.17556/jef.08804

Estriegana, R., Medina-Merodio, J. A., & Barchino, R. (2019). Student acceptance of virtual laboratory and practical work: An extension of the technology acceptance model. *Computers & Education, 135,* 1-14. https://doi.org/10.1016/j.compedu.2019.02.010

Fan, X., & Chen, M. (2001). Parental involvement and students' academic achievement: A meta-analysis. *Educational Psychology Review, 13*(1–22). https://doi.org/10.1023/A:1009048817385

Ferketich, D. (1991). Focus on psychometrics aspects of item analysis. *Research in Nursing & Health, 14*(2), 165–168.

Fraenkel, J.R., Wallen, & Hyun, (2011). How to design and evaluate research in education. New York: McGraw-Hill Humanities/Social Sciences/Languages.

Ganasen, S., & Shamuganathan, S. (2017). The effectiveness of physics education technology (PhET) interactive simulations in enhancing matriculation students' understanding of chemical equilibrium and remediating their misconceptions. In: Karpudewan M., Md Zain A., Chandrasegaran A. (eds). Overco. Springer. https://doi.org/10.1007/978-981-10-3437-4_9

Gökulu, A. (2013). Bilgisayar destekli öğretimin etkisinin incelenmesi ve maddenin tanecikli yapısı konusu ile ilgili öğrencilerin kavram yanılgılarının tespiti. *The Journal of Academic Social Science Studies, 6*(5), 571-585.

Guzman, J.L., Joseph, B. (2021). Web-based virtual lab for learning design, operation, control, and optimization of an anaerobic digestion process. *Journal of Science Education and Technology 30,* 319–330. https://doi.org/10.1007/s10956-020-09860-6

Harrison, A. G., & Treagust, D. F. (2000). Learning about atoms, molecules, and chemical bonds: A case study of multiple-model use in grade 11 chemistry. *Science Education, 84,* 352-381.

İlhan, N., & Hoşgören, G. (2017). Fen bilimleri dersine yönelik yaşam temelli başarı testi geliştirilmesi: Asit baz konusu [Developing of context based achievement test towards science: Acids and bases]. *Fen Bilimleri Öğretimi Dergisi, 5*(2), 87–110.

İlhan, N., Sadi, S., Yıldırım, A., & Bulut, H. (2009). Kimya öğretmen adaylarinin laboratuar uygulamaları hakkındaki düşünceleri[Candidate chemistry teachers ' opinions about laboratory practice]. *Kastamonu Eğitim Dergisi, 17*(1), 153–160.

İlyasoğlu, U., & Aydın, A. (2014). The effect of computer assısted teachıng on the scıence and technology teacher candıdates' achıevement ın the dırect current cırcuıts teachıng. *Kastamonu Eğitim Dergisi, 22*(1), 223-240.

Jia, F., Sun, D., & Looi, C. (2023). Artificial intelligence in science education (2013–2023): Research trends in ten years. *Journal of Science Education and Technology, 33,* 94–117. https://doi.org/10.1007/s10956-023-10077-6

Karaçöp, A. (2012). Maddenin tanecikli yapısı konusunun öğretiminde bilgisayar destekli öğretimin öğrencilerin akademik başarılarına, tutumlarına ve kalıcılık düzeylerine etkisi. Yayımlanmamış Yüksek Lisans Tezi, Gazi Üniversitesi, Ankara.

Karaduman, B. & Emrahoğlu, N. (2011). "Maddenin tanecikli yapısı" ünitesinin öğretiminde, bilgisayar destekli ve bilgisayar temelli öğretim yöntemlerinin, akademik başarı ve kalıcılığa etkisi. *Kastamonu Eğitim Dergisi, 19*(3), 925-938.

Kiraz, A. (2014). Yapay zeka destekli sanal laboratuvar tasarımı: çekme deneyi uygulaması (Doktota Tezi). Yükseköğretim Kurulu Başkanlığı Tez Merkezi (Tez No: 379548). Sakarya Üniversitesi.

Lawson, A.E. (1995). Science teaching and the development of thinking. Belmont, CA: Wadsworth.

McMillan, J. H., & Schumacher, S. (2006). Research in education: evidence-based inquiry (6th edition). Pearson Publishing.

MEB. (2018). Fen bilimleri dersi öğretim programı. Ankara: Talim Terbiye Kurulu Başkanlığı Yayını.

Okumuş, S., Öztürk, B., Çavdar, O., Karadeniz, Y., & Doymuş, K. (2016). fen bilgisi öğretmen adaylarının fiziksel ve kimyasal olaylarda maddenin tanecikli yapısı ile ilgili anlamalarının belirlenmesi. *E-Kafkas Journal of Educational Research, 3*(1), 64-78.

Özdener, N. (2005). Deneysel öğretim yöntemlerinden benzetişim (simulatıon) kullanımı. *The Turkish Online Journel of Educational Technology, 4*(4), 93-98.

Özmen, H. (2004). Maddenin tanecikli yapısı ile ilgili alternatif kavramaların tespitinde farklı veri toplama araçlarının birlikte kullanımı. *Journal of Research in Education and Teaching, 3*, 15-28.

Ramirez, J., Soto, D., López, S., Akroyd, J., Nurkowski, D., Botero, M. L., ... & Molina, A. (2020). A virtual laboratory to support chemical reaction engineering courses using real-life problems and industrial software. *Education for Chemical Engineers, 33*, 36-44. https://doi.org/10.1016/j.ece.2020.07.002

Renshaw, C. E, & Taylor, H. A (2000). The educational effectiveness of computer-based instruction. *Computers and Geosciences, 26*(6), 677-682.

Ruttena, N., Van Joolingen, W., R. & Van der Veena, J., T. (2012). The learning effects of computer simulations in science education. *Computers & Education, 8,* 136–153. https://doi.org/10.1016/j.compedu.2011.07.017

Smetana, L. K., & Bell, R. L. (2012). Computer simulations to sup- port science instruction and learning: A critical review of the literature. *International Journal of Science Education, 34*(9), 1337–1370.

Udin, W. N., Ramli, M., & Muzzazinah (2020). Virtual laboratory for enhancing students' understanding on abstract biology concepts and laboratory skills: a systematic review. *Journal of Physics: Conference Series*, 1521, 1-5.

Yılmaz, M., & Eren, A. (2014). Sınıf öğretmen adaylarına basit elektrik devreleri konusunun simülasyon ve laboratuvar uygulaması teknikleriyle öğretimi. *Trakya Üniversitesi Eğitim Fakültesi Dergisi, 4*(2), 84-99.