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Effectiveness of A Simulated Thermodynamics Lab in A Grade Eight Lyceum Class

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Abstract

We examine the use of PhET (University of Colorado Physics Education Technology) simulation labs in developing conceptual understanding of introductory thermodynamics by eighth grade students. Pedagogical experiments were conducted at the Baku European Lyceum, a gifted / magnet school in the capital of Azerbaijan. Results showed that virtual laboratories can play a crucial role in lyceum students' thinking and creative abilities and their acquisition of more in-depth knowledge and skills on thermodynamics. We also found that simulations have many appropriate advantages in learning and teaching lyceum thermodynamics, and list seven such.

Keywords: heat, thermodynamics, lyceum, PhET, physics lesson, virtual laboratory, middle school

INTRODUCTION

Since the 1970s advent of personal computers, simulations (or virtual laboratories) appeared first in medical instruction, then with the 1990s advent of web protocols (http://) didactic physics simulations were developed by multiple pedagogues (Sharifov, 2020). In 2002, Nobel Physics Laureate Carl Wieman founded the Physics Educational Technology (PhET) interactive simulations project at the University of Colorado and now during the pandemic that site has served aver 800 million simulations to physics learners worldwide (phet.colorado.edu).

Many scholars of physics learning and pedagogy have reviewed and determined the impact of simulation practices on lesson organization processes, which positively affects the acquisition of in-depth knowledge by students (Finkelstein *et al*. 2005; Gonzalez *et al*. 2002; Adam *et al*. 2020). Unsurprisingly, methods of working with virtual courses has also been developed (Gonzalez *et al*., 2002).

Scholars have also documented the use of simulations in students' acquisition of conceptual knowledge of physics on the pheno-mena of mechanics (Hestenes & Halloun, 1995; Safitri, Fahrudin, & Jumadi, 2020), electricity (Escobar, Sanchez, Beltran, Hoz, & Gonzalez, 2016; Gonzalez *et al.* 2018; 2019; 2019a), and heat (Gunawan *et al.* 2019; Hermansyah *et al.* 2019).

Gunawan *et al.* (2019) disclosed the virtual laboratory's effects in studying physics on gender differences. They observed high creativity in children of both sexes after using simulated labs, and they found that male students were more creative than female students.

Gustaffson (2004) emphasized the importance of simulation activities in distance learning of physics. Jiri (2015) determined that simulations were helpful despite certain shortcomings in remote and virtual laboratories.

Other have identified the virtual laboratory's positive impact on improving robotics (Latinovic, Deaconu, Latinovic, Maleševic, & Barz, 2015; Xie, Zhou, Shi, & Jia, 2018; Lin, San, & Ding, 2020).

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In reviewing the above pedagogical studies of simulation experiments, it was established that such studies were not yet conducted in specialized middle schools or lyceums and in particularly concerning the teaching process of thermal phenomena among lyceum students. Therefore, in this article, the virtual laboratory's effect on teaching thermal phenomena being a part of physics subject was studied among the lyceum's eighth-grade students.

METHOD

A pedagogical experiment was conducted at the Baku European Lyceum. The experiment consisted of three stages: confirmation, search, and formation. At the first stage of the study, the analysis of normative documents in higher education, design of educational and research activities of VII-XI grade students, ICT and related problems were carried out. The state of scientific-methodological and psychological-pedagogical literature and the teacher's readiness to implement these processes were examined—one of the main problems that arise while teaching physics subject in VIII grades of the lyceum.

To help students understand thermodynamics, the teacher should develop the skills and techniques in physical classroom laboratories. Nevertheless, in some cases, physics teachers are concerned with student safety risks due to hot apparatus and fluids. Following discussions with the physics teacher in Baku European Lyceum, it was planned to opt for virtual labs for studying these thermodynamics.

Lyceum students are magnet school students with exceptional talent, so student knowledge and skills in research activities in the lyceum and the teacher's preparation for solving this type of problem were analyzed, and the research problem, its goals and objectives were determined.

The purpose of the first stage of the study was to determine the problems of conducting students' laboratory work in physics teaching at the lyceum and the physics teacher's readiness for this professional activity. There-fore, pre-activity assessments were held with physics teachers and students of the lyceum. Students were asked the following questions related to heat:

1) The room temperature is 30℃. When one touches iron metal, the metal feels cold. How do you explain this?
2) When we go outside in winter, we feel cold. How do you explain this?

At the second stage of the study, a model for fostering student experimentation activity inside a virtual laboratory within physics teaching was developed, and a research hypo-thesis was formulated. The student simulation laboratory study plan was developed to provide the necessary resources and specific education-nal and methodological tools for the physics teacher to design and organize students' activi-ties within the virtual laboratory's application. As a part of our pedagogical experiments, groups were divided into control and experimental groups, each of which had 25 VIII class stu-dents. Control groups received regular physics teaching instruction, and simulations labs were implemented in the experimental or treatment groups.

Afterwards, the student laboratory experiments were analyzed by scoring student performance tasks, including three simple, three relatively simple, two relatively complex, and two complex tests. This distribution of tasks was selected as the evaluation criteria for the preparation of learning assessment tasks.

At the third stage of the study, the diagram that reflects the survey results were formulated. These results were analyzed and studied in SPSS and Excel.

The University of Colorado Boulder PhET simulation "Energy forms and changes" was used during this study on for experimental groups of middle school students (Figure 1).

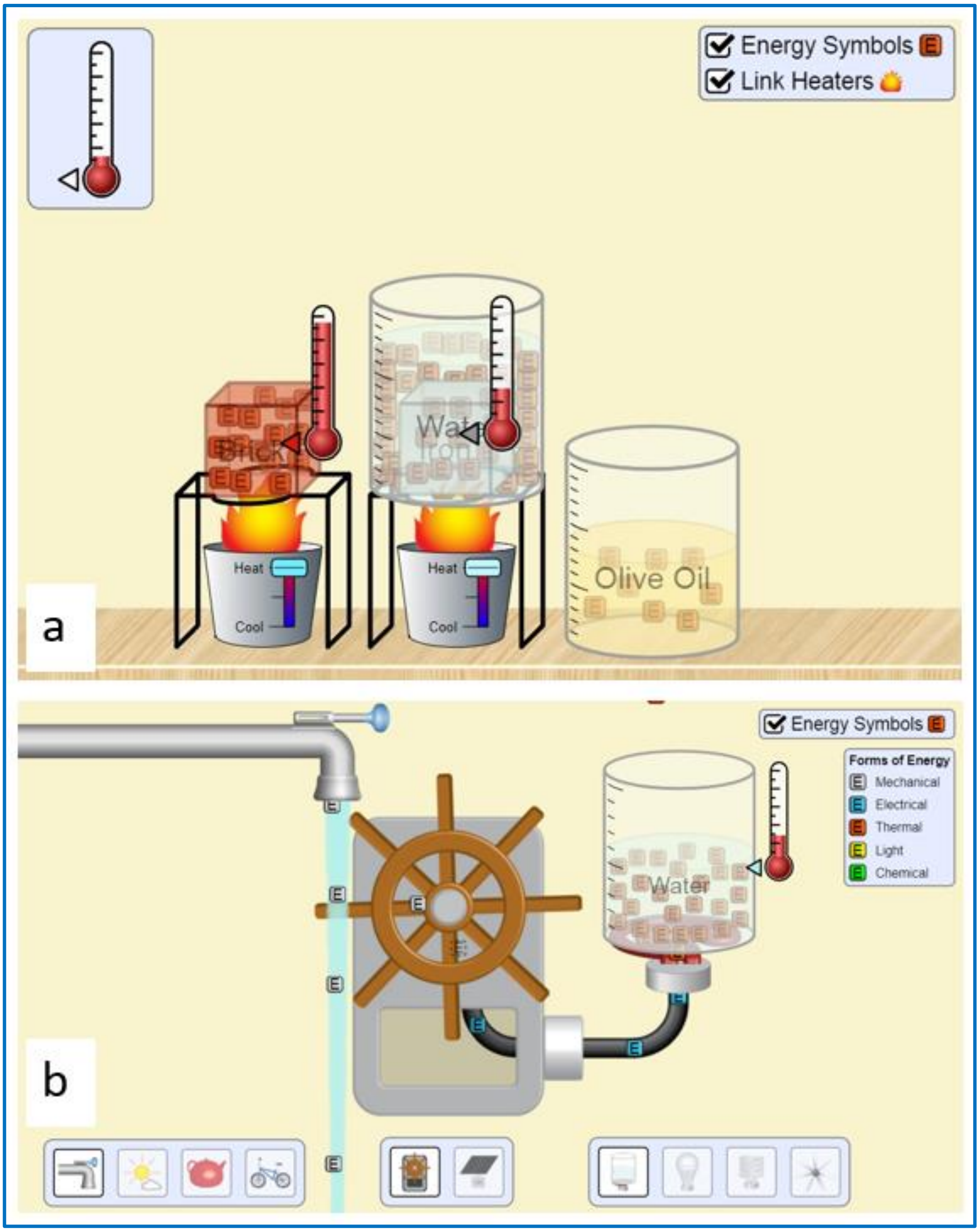

Figure 1. Virtual lab for "Energy forms and changes."
(https://phet.colorado.edu/sims/html/energy-forms-and-changes/latest/energy-forms-and-changes_en.html)

Using this PhET simulation, teachers and students can clearly show the essence of energy transformations and their practical use. In general, from a methodological point of view, simulation operators can readily and success-fully demonstrate how much heat transfers from one type of energy to another kind and how well heat capacity plays a role in our daily life.

To determine the impact of the role of simulation labs within the pedagogical experiment, both control and experimental groups from the eighth-grade students of the lyceum were given test tasks, including the ten questions shown in Figure 2. Results are reported and the conclusions are shown in Figures 3- 5.

Boy □ Girl □

1. **How much heat do you need to heat the iron cube of mass of 2 kg from 20 ℃ to 320 ℃? (The specific heat capacity of the iron is 460 C / (kg ℃)**
   A) 200kC B) 276 kC C) 300 kC D) 376kC E) 270kC

2. **How will the internal energy change if any system works by itself?**
   A) do not change B) firstly decrease then increase C) decrease
   D) firstly increase then decrease E) increase

3. **In which substance is the convection process impossible?**
   A) only in liquid B) only in gas C) only in solid D) liquid and gas E) solid and liquid

4. **Amount of heat:**
   A) internal energy, which does not arise and disappears
   B) the energy of the forward motion of ideal gas molecules
   C) the sum of the energies of their interactions during the constant movement of ideal gas molecules
   D) the internal energy of anybody at a constant temperature
   E) the transferable part of internal energy during heat exchange

5. **How much water with a temperature of 86 °C should be added to 500 g water with a temperature of 6 °C so that the final temperature of the mixture is 36 ° C (assume no heat loss)?**
   A) 5 kg B) 4,26 kg C) 2 kg D) 25 kg E) 10 kg

6. **The temperature of an object depends on…of the molecules that make up it.**
   A) the number B) the size C) the layout D) the distance between them E) the speed

7. **Why in the summer does the weather on the seacoast get cooler? Justify your answer by writing an essay.**

8. **When a body absorbs radiant energy … Complete the sentence.**
   A) the only temperature of the body reduces
   B) the internal energy and temperature of the body increase
   C) the internal energy and temperature are unchanged
   D) the internal energy increases, however, its temperature does not change
   E) the internal energy decreases, however, its temperature increases

9. **What does the heat balance equation describe?**
   A) The initial temperature of the object
   B) The special heat capacity
   C) The final temperature of the mixture of the two substances
   D) The law of conservation of Internal Energy
   E) The specific combustion temperature of the fuel

10. **What are similarities and difference between specific heat capacity and thermal capacity? Justify your answer by writing an essay.**

Figure 2. Tasks given to Control and Experimental groups

RESULTS AND DISCUSSION

During the before-instruction discussions on the topic of heat in VIII grades at lyceum, students answered as follows:

1) **The room temperature is 30℃. When one touches iron metal, the metal feels cold. How do you explain this?**
   - *It happens because the iron gives a lot of heat*

- Less heat comes out from the board.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Results	Equal variances assumed	2,283	,153	-1,688	14	,114	-9,00000	5,33185	-20,43567	2,43567
	Equal variances not assumed			-1,688	9,588	,124	-9,00000	5,33185	-20,94972	2,94972

Figure 3. Independent *t*-test results of control and experimental group students' responses

2) When we go outside in winter, we feel cold. How do you explain this?

- The cold comes to us from the outside, and the temperature of our body decreases.
- The heat transfer of our body is great.

From the answers to the questions, it became clear that although students have specific knowledge and knowledge on this topic, they find it challenging to explain thermal phenomena' physical nature. After the simulation laboratory (Figure 1) was applied during the teaching process of heating the experimental group. Based on simulators shown in Figure 1, virtual experiments were widely used in different stages of the physics lesson in experimental groups. Then, both the control and the experimental group students completed the instrument shown in Figure 2.

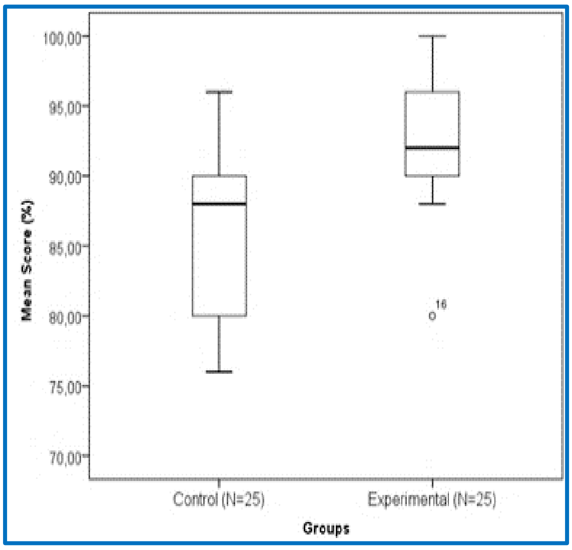

Figure 4. Mean test scores, in percentages, for both control and experimental groups

Independent *t*-test results of students' responses are shown in Figure 3. As can be seen, there is no significant difference in test results between the control and the experimental groups. However, Figure 4 shows that the average score for the control group is lower at 83% ± 13.8% than for the experimental group at 92% ± 6%.

From the analysis of the mean test, it can be seen that the experimental and control groups had approximately the same knowledge. This fact is also proved by the value of p = 0.124 (Figure 3). However, individual differences arose in responding of both groups to difficult questions (Figure 5). This enhancement is consistent with several scholars' findings, whose papers revealed the beneficial effect of virtual labs on students' development of in-depth information (Finkelstein et al. 2005, Gonzalez et al. 2002, Adam et al. 2020).

Hence an item-by-item re-analysis was undertaken for the experimental and control group student responses to the instrument given in Figure 2.

By focusing on the first question, which is a relatively tricky question, we see that the control class answered correctly 76%, and the experimenttal class 92%. This task is the calculation type of the topic on the specific heat capacity and amount of heat.

If we look at the second task, which is a simple question, we can see that 92% of both classes answered this question correctly. Most students obsessing knowledge of internal energy can answer this question precisely.

Then, 88% of the experimental class students and 84% of the control group students responded correctly to task No 3, which is considered a relatively simple question.

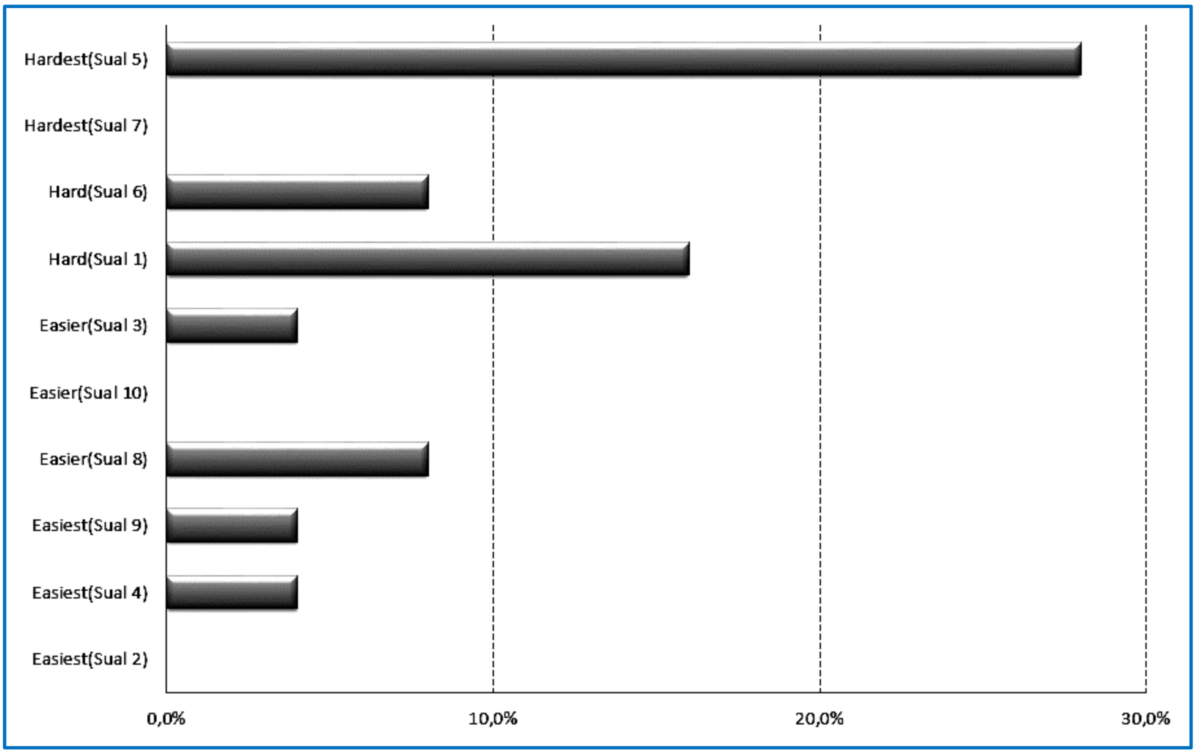

Figure 5. The difference between experimental and control groups' responses to tests

The simple question number four presented to the students in the test task was answered correctly by 100% of the experimental group students and 96% of the control class students. However, most changes were observed in answering the fifth test assignments, which were considered difficult question. Nevertheless, 80% of the experimental class students and 52% of the control class students responded to this question correctly. A significant positive change has occurred while doing this item, which is considered a series of difficult computational nature questions. We claim that student responses to question number four were positively changed because of the influence of virtual experiments. Because of this question's abstract yet central connection to all thermodynamic phenomena, its explanation and investigation are accompanied by great interest, which plays a vital role in a deep understanding of this topic.

The sixth question is another relatively difficult theoretical question related to an object's temperature, and 88% of the control class students and 96% of the experimental class students responded to this task correctly.

The seventh question was a particularly challenging problem, and before instruction, students were not able to accurately answer this open-ended question. Nevertheless, most of the students in simulation classes responded to this question correctly. Interpretable student answers that are close to correct are as follows:

1. *Water absorbs the hot air, the sea cools;*
2. *Water absorbs a large amount of the heat;*
3. *Due to the high heat capacity of water.*

The eighth question was relatively simple. One can see that 96% of the experimental class students and 88% of the control class students answered correctly.

The 9th question in the test tasks is also a simple question and an informative question about heat balance. So, 88% of the control class students and 92% of the experimental class students answered this question correctly.

The 10th question, our second open-ended question, was presented to students as if it were a relatively simple question. However, students did not answer this question as well as they did in the seventh question. The main content of this question is about heat and specific heat capacity. Most students replied *"The heat and specific heat capacities is the energy spent heating and cooling the substance"* and similar under-discriminated statements. However, post simulation, student descriptive answers to the 10th question were sharply improved.

In the course of pedagogical experiments and observations, we concluded that the simulation or virtual laboratory positively affects students' thinking. Considering paragraph No 1.0.33 on the Azerbaijan education law (Law of the Republic of Azerbaijan on education) states the lyceum is a public education institution that provides educational services in the relevant areas for gifted students at the level of general and complete secondary education. For this reason, students studying at the lyceum go through various selection rounds. Students enjoyed the implementation of the virtual lab and had fun doing lab work. This experiment taught students to show interest in learning, solve problems independently, and draw conclusions. Similar simulation laboratory improvements was also observed in papers of Gunawan et al. (2019) and Hermansyah et al. (2019).

Statistical analysis was conducted after the application of the test (Figure 3, 4). To compare the data, the test was used with two tails. The purpose of this test is to determine whether there is any significant difference between the responses of the two groups of students in this study. A 95% confidence level ($\alpha = 0.05$) was used for all comparisons throughout the course. The mean scores of the test were 83 ± 13.8 for the control group and 92± 6 for the experimental group.

As shown in Figure 5, students in the control and experimental groups responded to the 2, 3, 4, 6, 8, 9 tests with slight differences (4-8%). Such a small difference is due to the high level of theoretical knowledge that these select students possess in both groups upon arrival, which was expected. However, the most significant difference was observed in the answers to the first (16%) and 5th (28%) questions. This fact can also be attributed to the virtual laboratory's positive impact on students' analyses and application of thermal phenomena categorizations and the bookkeeping associated with thermal phenomena calculations – perhaps the conceptual essence of thermodynamics at the lyceum. Therefore, the students who understood the physical meaning of the heat capacity could write and solve a question regarding it.

From the open-ended questions, one can conclude that a numerous correct answer of the experimental group students to the 7th and 10th questions is associated with a more significant impact of the virtual labs on the students' the logical, critical and creative thinking. Besides, if we consider that the implementation of virtual labs may play an essential role in developing practical skills, the increase of correct answers to these questions in the experimental group proved the high positive impact of this type of laboratory on students' practical skills development.

During pedagogical experiments, we found that the main advantages of this simulation are listed below:

1. simulations may be flexibly used in many different stages of a lesson, such as motivation, creativity, and even homework
2. simulations protect students from some hazards of dangerous lab experiments;
3. simulations allow students to display highly accurate events and results that cannot be measured with simple laboratory tools and require complicated and expensive equipment;
4. simulations help students and teachers study and prepare lab experiments anytime and anywhere;
5. simulations bs allow the student to control the initial data of the investigation, change various operations and track changes in the result without treatment and without risk;
6. simulations create the ability to record all results electronically, help them eventually analyse and share the results with other participants (including during a pandemic);
7. simulations allow simultaneous comparative analysis of various laboratory works;
8. simulations help to attract student's attention and provide high motivation during the lesson.

CONCLUSION

This article deals with the theoretical and practical implications of using simulations or virtual laboratories individually and in a group to learn middle school thermodynamics. Students used PhET simulations to gain in-depth knowledge and skills later employed answering relatively tricky and challenging test questions and tasks. The results showed that virtual experiments are an indispensable online platform for the safe implementation of the practical part of physics in any emergency that may occur in the world and the development of practical skills of specially gifted students.

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