

Virtual Educational Physics Experiment as a Means of Formation of the Scientific Worldview of the Pupils

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Abstract. An important component of the general aim of secondary education is the formation of a scientific worldview of the youth; it is based on empirical and theoretical knowledge about the world as a whole. The most fundamental laws and principles of nature compose a comprehensive *physics picture of the world*. An important part of formation of the picture in the pupils' minds is experimental verification of the fundamental laws of nature.

The analysis of a significant number of currently available in the domestic market physics-based software products has shown that they are presented in the form of electronic tutorials, electronic libraries, and various virtual physics laboratories designed to study models of physics processes or phenomena.

The authors prove the definition of virtual educational physics experiment (VEPE) as a kind of educational physics experiment that is carried out using digital models of phenomena and processes, multimedia, interactive animations, and simulations. In accordance with the didactic aim, the VEPE is divided into demonstration and laboratory.

Application of the VEPE during the study of molecular physics shows the suitability of its using for a new material explaining, the knowledge updating, and determination of the degree of formation of the pupils' subject competence.

The conclusion about necessity of the search of optimal forms and methods for integrating real and virtual experiments is made by the authors; the integration will promote both the visibility and accessibility of material perception and the development of the pupils' creative abilities and various forms of thinking.

Keywords: virtual educational physics experiment, scientific picture of the world, virtual physics laboratory, interactive model, physics simulation.

1 Introduction

Problem statement. The General Provisions of the Law of Ukraine «On Education» state that one of the fundamentals of state policy in the field of education is its scientific

character [1], the key component of the aim of secondary education is the formation of ideological orientations of pupils [6], [27].

The concept of the worldview is a general scientific category; it is defined in academic dictionaries as «a particular philosophy of life or conception of the world» [8], «the system of standpoints on the objective world and the place of man in it» [7], «a comprehensive conception or apprehension of the world especially from a specific standpoint» [28], and «is based on experimental and theoretical knowledge about the world as a whole, which is characterized by objectivity, verity, general significance, purposefulness, reproducibility, determinism, necessity, efficiency of changes in the natural-historical reality» [19].

The scientific worldview mainly concerns the modeling of the world and should provide a scientific explanation of general philosophical questions (1) what is? ontology (model of reality as a whole); 2) where does it all come from? explanation (model of the past); 3) where are we going? prediction (model of the future); 4) what is good and what is evil? axiology (theory of values); 5) how should we act? praxeology (theory of actions); 6) what is true and what is false? epistemology (theory of knowledge)); the worldview is founded and verified by observations and experiments [32, p. 8].

The basis of the scientific worldview is *the scientific picture of the world* (SPW); it is an integral system of representation of general properties and rules of nature, consequence of the synthesis of basic natural scientific concepts and principles [19, p. 326 – 327]. Its structure consists of the conceptual and sensory-imaged components. The *conceptual component of the SPW* includes philosophical categories (matter, motion, space, time, etc.), principles (material unity of the world, determinism, etc.), general scientific concepts and laws (for example, the law of conservation and transformation of energy) as well as fundamental concepts of individual sciences (field, substance, universe, population, etc.). Explanation of the basic laws and properties of nature in the SPW is carried out through visual images. They form the *sensory-imaged component of the SPW* that is a set of visual representations of certain objects and their properties (for example, a planetary model of an atom, an expanding model of the Universe, etc.) [25, p. 37].

Fundamental science that studies the general laws that describes regularity of phenomena in the material world, creates basis of the world understanding at different levels of knowledge about the nature, and provides a general justification of the scientific picture of the world is *physics*; the *physics picture of the world* combines the most fundamental laws and principles of nature [14, p. 3-5, 6]. Therefore, it is physics that is positioned in the rank of universal scientific picture of the world in the history and philosophy of science and technology of the twentieth century [25].

Physics is an experimental science. Therefore, an important part of the formation of the physics picture of the world is the study and implementation of physics experiments, which are carried out by means of demonstrations and laboratory experiments during traditional forms of learning [2, 3]. However, it is impossible to reproduce most of the fundamental experiments in the classroom due to the complex equipment or methodology, the interval of time, the non-compliance with safety standards, impossibility of creating experimental conditions in educational institutions etc.

An important instrument of physics as a science is to simplify the consideration of real complex objects by presenting them in the form of models. It creates the conditions for solving the methodical problems by implementation of a virtual physics experiment in the educational process. Computer programs allow to simulate the physics process as well as to change the conditions and parameters of its performance [16]. The mathematical basis of the virtual model enables the obtaining of idealized values of physics quantities and creates opportunities for the laws checking and identifying rules in the «pure form» without any errors during the natural experiment.

Obviously, such a software product is sensitive to changes of all types of information technology (network, cloud, multimedia). The above-mentioned reveals significant opportunities for involving all participants of the educational process in the «vertical-horizontal» educational interaction; the work can be carried out in the classroom and / or using remote access, individually and / or in the group, independently and / or under the supervision of the teacher depending on the type of educational physics experiment, its aims, tasks, forms, and methods of study [13].

The conducted research has shown that the virtual physics experiments are widely used in the educational process of secondary and higher schools but the theoretical basis and didactic approaches to their use as a means of forming of the scientific picture of the world in the subjects of study is a poorly studied pedagogical problem.

Analysis of recent studies and publications. An analysis of literary sources has shown that certain unrelated theoretical and practical aspects of this problem are revealed in a large number of scientific publications of domestic and foreign scientists at the end of the XX – early XXI century. The results of research on the problems of formation of the scientific worldview and the scientific picture of the world are presented in the works of William W. Cobern, Michael R. Matthews, Hugh G. Gauch Jr., M. Ginzburg, S. Goncharenko. Simulation of the virtual physics experiment was considered by M. Golovko, Yu. Zhuk. The influence of the virtual experiment on the attitude of students to physics was studied by A. Alexiou, Z. Ayoubi, E. Bozkurt, C. Bouras, E. Giannaka, M. Faour. Application of virtual physics experiment in education was considered by J. Mirçik, A. Saka, J. Singh, Ya-feng LI, Z. Zacharia. Integration of a real and virtual educational physics experiment was studied by S. Velichko, I. Salnik, I. Slipukhina. Preparation of the physics teachers for use of the virtual physics experiment in classroom was revealed by V. Charko. Didactic principles and programs for video analysis of physics phenomena were studied by J. Chernetsky.

It was found that the following directions of the use of virtual physics experiment as the demonstration of physics experimentations, phenomena, structure, and properties of real and artificial (technical) objects as well as various simulations have the most recognition in the methodology of physics education at present [18, 33].

According to V. D. Sharko, a virtual physics experiment in the physics teaching can work as a means of cognition, the provision of components of «ready» knowledge, the visual aids; depending on the pedagogical purpose, it accompanies to other ways of the «ready» knowledge presenting, acts as a simulator for the individual cognitive abilities processing, means of testing the level of formation of knowledge and skills of pupils [24].

The research has exposed that a number of software packages intended for conducting of virtual educational experiments is presented now in the market of Ukraine. It has been found out that there are almost 40 softwares for physics study that are created and used in the educational process (Table 1).

Table 1. List of software recommended by the Ministry of Education and Science of Ukraine for physics study

Manufacturer	Name of the software
«Kvazar – Micro Tech» http://www.kmcore.com/uk	«Physics 7», «Physics 8», «Physics 9», «Physics 10», «Virtual physics laboratory 7–9», «Virtual physics laboratory 10–11», «Electronic visualization library 7–9», «Electronic visualization library 10–11», «Electronic task book 7–9»
«Kontur Plus» e-mail: public@iclub.rv.ua	«Physics» for independent work, «Virtual physics laboratory» for independent work, «Physics 7», «Physics 8», «Physics 9», «Virtual physics laboratory – 7th grade»
«Transportation systems» http://media.slav.gov.ua ; http://shkola.ostriv.in.ua	«Physics 11», «Physics 7», «Virtual physics laboratory. Physics 7th grade»
«Rozumniki» http://rozumniki.net	«Physics 7», «Physics 8», «Physics 9», «Virtual physics laboratory – 7th grade», educational software program «Physics 11», «Physics to 200 points. Tests », «Physics. Study seriously»
«Nova shkola » http://novashkola.com.ua	«Physics 7», «Physics 8», «Physics 9», «Physics 10», «Physics 11», « Virtual physics laboratory – 7th grade»
«Osнова» http://book.osnova.com.ua	«Electronic designer lessons. Physics 7–11»
«Study Buddy» http://www.studybuddy.od.ua	«Your personal tutor. Video lessons.7–11 th grade»
«Atlantic – Records» http://ukrprog.com	«Physics for entrants»
«Soroka Biloboka» http://www.soroka-tm.com.ua	«Physics to 200 points»

The analysis has showed that existing educational softwares for physics are presented as electronic tutorials, electronic visualization libraries, and virtual sciences laboratories. Thus, the virtual physics laboratory is a software tool designed to simulate pupils' work in a real physics laboratory during the study of physics processes or phenomena [12].

As can be seen from Table 1, only the «Kvazar – Micro Tech», «Kontur Plus», «Transportation systems», and «Rozumniki» softwares have the «Virtual Physics Laboratory» complex. Such software makes it possible to perform a laboratory work using an imitation model of a physics phenomenon or process, independently select equipment for laboratory work, and change the input parameters of the experiment.

However, despite the popularity among teachers, virtual laboratories that are part of the software have certain disadvantages [5]. Only a small amount of them is intended for use during an educational physics experiment. At the same time, almost all such softwares do not use video clips and video observations of natural observations, real experiments are replaced by animations (in many cases of poor quality) or computer models [23]. In this context, as shown in the works of I. S. Chernetsky, special attention is deserved for a program Video Analysis Tracker, which is freely available on the network and allows to explore real processes and build their mathematical models based on video analysis [4].

On the other hand, domestic and foreign markets propose software products that almost completely satisfy the requirements of users both in terms of structure and functionality. These products include virtual on-line labs. They allow you to conduct experiments without buying additional programs. For example, the purpose of the «*Physics Education Technology*» package [21] is to interactively simulate physics phenomena for their demonstration during the educational process.

This resource represents virtual laboratories that can display various natural phenomena as well as interactive mathematical tools. Virtual labs contain one or more tasks as well as a set of the elements needed to solve them. The main purpose of the demonstrations is visualization and explanation of the phenomena but not testing the knowledge and skills of the user. The search for virtual labs in this portal can take place via the subject, via the level of education (primary, secondary, high school, and higher education), via devices (computer, tablet), and via interface translations.

«*VirtuLab*» (<http://www.virtulab.net/>) is one of the largest collections of virtual experiments in various disciplines. The main unit of this portal collection is a virtual experiment. Each video segment allows pupils to conduct an experiment that has an educational purpose and a clear task. All the tools and objects needed to get the result are offered to the user.

Interactive simulations for primary and high school pupils are provided on «*Gizmos*» [11]. This portal contains over 400 simulations that can be hosted in your own virtual classroom.

The domestic product *Steam-laboratory* deserves particular attention «*MANLab*» (<https://stemua.sciens>). It is the center of real and virtual study research aimed at supporting and developing STEM-education in Ukraine. This laboratory specializes in conducting research in the field of natural sciences: physics, chemistry, biology, geography, astronomy, ecology, mineralogy. Information and technology components are the

educational programs, methodical materials, virtual laboratories. The site is Ukrainian-language. Its resource filling is constantly updated. A user can see in detail the digital equipment needed for a real experiment and its digitization. The video section contains lectures and experiments on the main topics of physics that are convenient for use in the stages of explaining the new material.

Several hundred animations from all sections of the school physics course are collected on the site «*Physical bag*» (http://fizikasoloosh.blogspot.com/p/blog-page_39.html). However, you need to download to your computer and have a file player with the extension * swf. in order to play them.

At the same time, on-line softwares that do not require additional software such as «*Fowler's Physics Applets*» are more popular among consumers [10].

We need to mention The «*Electronic Workbench*» software (<https://soffamous.com/lucid-electronics-workbench/>), which is intended for simulation of digital and analogue electronic circuits and includes editing tools, simulations, circuit testing tools, and additional tools for analyzing models. Similar on-line features are provided by the «*Circuitlab*» software (<https://www.circuitlab.com/editor/#?id=7pq5wm>).

The «*Interactive Physics 2000*» computer educational environment (<https://www.design-simulation.com/IP/simulations.php>) is designed to create two-dimensional mechanical models. Models are created without programming by the computer mouse. Emulations of the mechanics of particles, springs, solids deformations, gravitational and Coulomb forces are possible with the help of Interactive Physics 2000.

Thus, virtual physics labs software tools and resources with the ability to conduct physics experiments are presented in large numbers in free access. The mentioned pedagogical possibilities are amplified by the high technology of modern software products, in particular, the possibility of their use on various gadgets in the «24/7» mode [26]. That obviously has positive effect to the educational interest and the desire of pupils to explore physics phenomena and processes independently turning virtual physics experiment into a valuable didactic means for forming the physics picture of the world.

However, the theory and methods of using a virtual physics experiment as a means of forming the scientific picture of the world in the subjects of education are little-studied pedagogical problem today.

The purpose of the article is to specify the content of the category of virtual educational physics experiment and to highlight its significance in forming the components of the scientific picture of the world for pupils.

2 The Results and Discussion

The term «Virtual Educational Physics Experiment» (VEPE) has not a well-defined meaning yet. The variety of definitions makes pay attention to the sense of this concept. It is composed of two main attributes: general: «educational physics experiment» and specific: «virtual».

In general, the experiment is considered as a method of scientific knowledge, a method of sensory-objective activity in science through which phenomena are studied in appropriately selected or artificially created conditions that can show the flow of processes in a clear form. Such observation is necessary to establish regular relationships between phenomena. [19, p. 117–118]. On the other hand, the experiment is made to demonstrate a known reality, examine the validity of a hypothesis, or determine the efficiency of something previously untried [29]. In the school course of physics, the experiment is considered as: a reflection of the scientific method of research in physics [17]; way of reproducing of physics phenomena with the help of special devices during lessons or extracurricular activities [6]. In this regard, the educational physics experiment acts as an organic component of the methodological system of learning, which ensures the formation of the necessary practical and research skills, personal experience of experimental activity of the pupils. It is the most important method and specific means of scientific knowledge.

The results of the research [23, 34] indicate that the physics experiment can be implemented in the following areas: 1) an independent form of a real experiment with subsequent programmed elaboration of its results (interaction «pupil – object»); 2) a natural study in conjunction with the use of digital complexes and computers (interaction «pupil – a digital measuring complex – an object»); 3) virtual experiment (interaction «pupil – model»). The first approach is appropriate in the case when the experiment is not limited by the capabilities of existing laboratory equipment. The second and third approaches allow to significantly expand the topic and quality of experimental research as well as to obtain more accurate results.

Continuing the clarification of the definition of VEPE, we turn to its specific feature «virtual» (from the Latin «virtualis» – possible, one that does not have physics embodiment [19], «not physically existing as such but made by software to appear to do so, ...carried out, accessed, or stored by means of a computer, especially over a network» [8]). Thus, a virtual experiment is called a computer experiment, which consists of simulation of phenomena, objects, research tools, and actions that a user must conduct in a real laboratory.

In the context of our study, we recognize the VEPE as a kind of educational physics experiment that serves as a means of physics processes and phenomena demonstrating or simulating with the help of a computer.

In accordance with the didactic aim and by analogy with the real physics experiment, the VEPE is divided into demonstration experiment and laboratory one (Fig. 1).

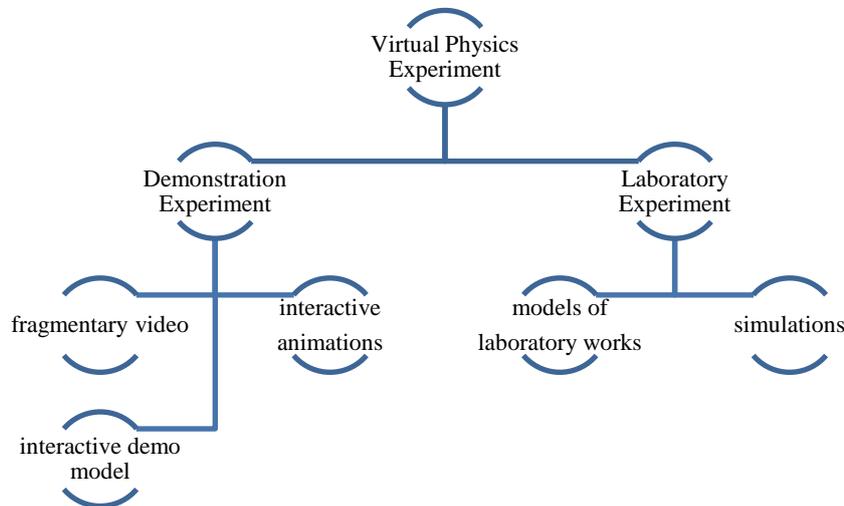


Fig. 1. Types of Virtual Educational Physics Experiment

Considering the VEPE as a didactic object, it should be noted that it is a method, form and means of study: the subjects of the study perform certain practical tasks (experiments) operating by the virtual images of physics objects, phenomena and research equipment that reproduce the appearance and functions of real objects. The VEPE is aimed at achieving the same didactic aims as the corresponding real physics experiment; it facilitates the formation of research skills using the devices and equipment of the modern physics laboratory as well as stimulates the interest of pupils as a technical and technological object.

Note that the use of VEPE is the best or the only possible way of study in a lot of situations: this is distance learning, the lack of the ability to conduct a real experiment (inaccessibility or complexity of equipment, time constraints). In addition, VEPE can be used for preparation of a full-scale experiment: to develop the necessary skills for studying the actual process (for example, studying isoprocesses, reviewing the thermal balance under conditions of mixing water of different temperatures, determining the focal length and optical force of a thin lens), to predict possible mistakes in the preparation and the conduct of the experiment (for example, the construction and research of the electric circuit, the construction and testing of the electromagnet), the methods of complex equipment handling (studying the structure and action of complicated optical devices, an eye model, the principle of the ion particles counter), observation of continuous and line substances spectra, observation of tracks of particles in a cloud chamber).

The VEPE in the educational process may be part of the laboratory work that is based on a virtual physics laboratory that simulates the main stages of the laboratory work and contains methodological instructions with theoretical information, tasks, technological map, and requirements for the report.

In order to determine the level of use of the virtual educational experiment in the educational process, an Internet survey of physics teachers of Kherson and Kherson region was conducted. The results of the survey are presented in the diagram (Fig. 2).

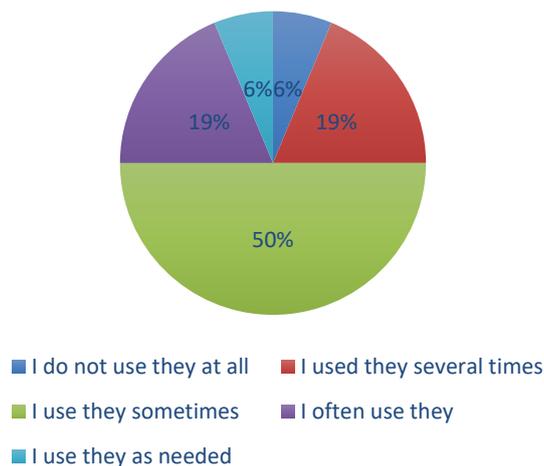


Fig. 2. The use of virtual software by physics teachers

The analysis of the teachers' answers affirms the low level of use of virtual technologies during physics study. The teachers give preference to virtual labs and a demonstration experiment; they practically do not use a virtual experiment at the stages of knowledge learning or at homework. The most complete and demanded products among the virtual means are: software tools of production «Kvazar – Micro Tech»; available on-line virtual laboratory works «Physics Education Technology», «VirtuLab», «Getaclass»; mobile tutorials (Toolbox Sensor Suite, Lab4Physics) (Fig. 3).



Fig. 3. The most demanded virtual software among teachers of physics

It should be noted that the high-quality VEPE must satisfy such requirements [9, 12, 24]:

- evident similarities with real physics devices and their real behavior in time and space;
- the course of the work and the results processing must not differ from the real experiment;
- in virtual labs as in real experiment, pupils should be faced with transient processes, the need for temporary exposure before the results obtaining;
- models should provide the possibility of random errors.

Taking into account the aforementioned, we give examples of the use of the VEPE in the educational process during Molecular physics study. Let us denote that the fundamental of molecular physics is the experiments of J. Perrin, O. Stern, R. Boyle, E. Mariotta, J. Charles, J. Gay-Lussac.

At the stage of actualization of the knowledge or when explaining new material, teachers often use demonstration fragmentary video. Thus, ManLab has selected in the educational environment four video experiments on the topic «Isoprocesses in gases»: demonstration of the experiment «Egg in a bottle», demonstration of the isobaric process, demonstration of gas isochoric heating, and demonstration of isothermal gas expansion (Fig. 4). Each process is accompanied by a graphical model [15].

The method of conducting the experiment «Isothermal expansion of gas» is not complicated; therefore, it can be performed at a lesson. However, if it is not possible, the video experiment can be offered to pupils as homework.

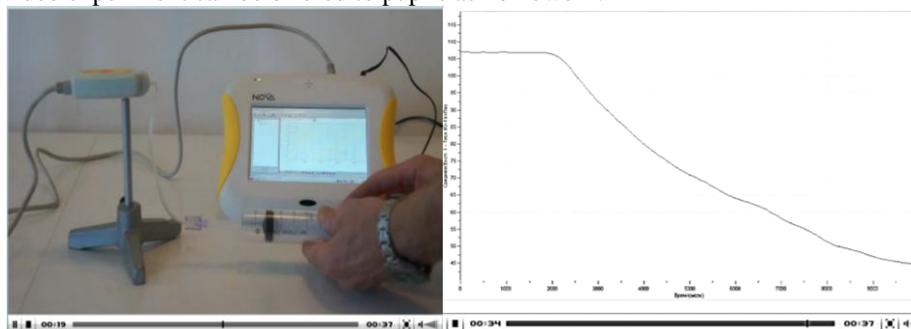


Fig. 4. Video demonstration of gas isothermal expansion in the ManLab educational environment

When studying the basic laws of the molecular-kinetic theory and their experimental verification, pupils are invited to observe the Brownian motion of a paint particle in water using the school microscope. However, school measuring instruments practically cannot display the trajectory of the particle motion or the path it traverses. However, if we take the Fowler's Physics Applets online resource animation [10], it gives an opportunity not only to show the trajectory of the particle but to change the amount of the substance particles and to investigate the change in the nature of the motion of a Brownian particle (Fig. 5).

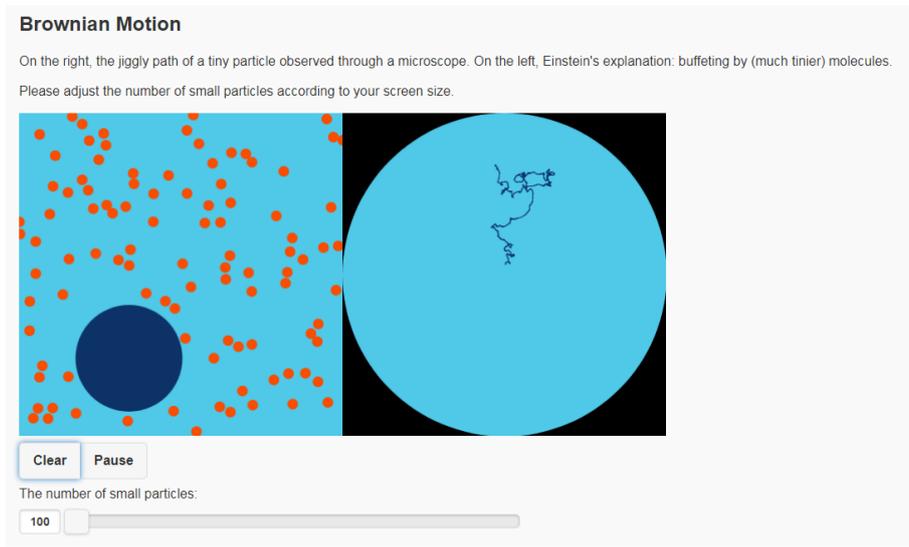


Fig. 5. Animation of the Brownian motion on the of Fowler's Physics Applets online resource

Using the model of particles motion at a certain temperature that is accessible on the resource «Gizmos» [11], pupils can explore the form of Maxwell's distribution of molecules by speeds for different gases and establish the dependence of the mean square speed of molecules on the temperature (Fig. 6). When studying the distribution function, the teacher can propose to pupils to establish a mathematical relationship between the values in this animation and verify the reliability of the established dependence by calculations of the speed numerical value. The task should be arranged in the form of a physics problem; the values necessary for calculation can be taken from the model condition.

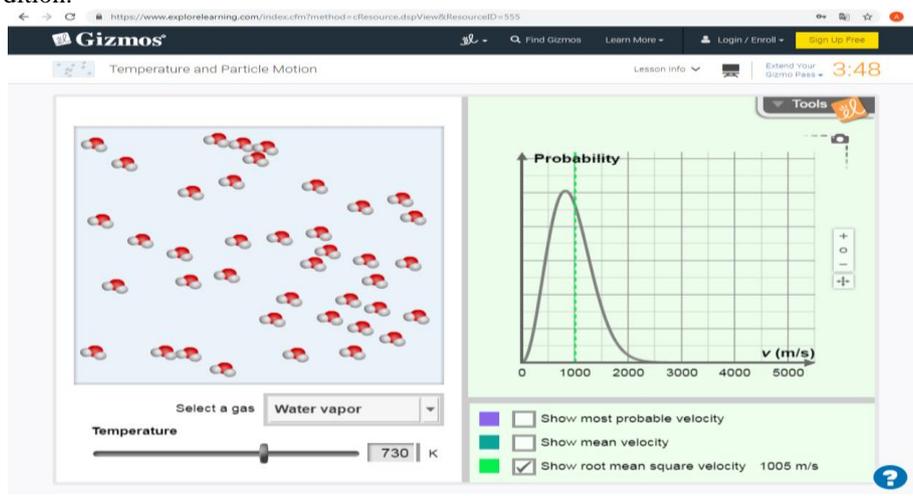


Fig. 6. Interactive model of Maxwell's distribution function

An essential element of the physics study is the laboratory works carrying out. The physics program for class 10 during the study of the topic «Molecular Physics and Thermodynamics» offers for the performance three laboratory works: one of the iso-processes study; determination of the coefficient of surface tension of the liquid; determination the modulus of elasticity of various substances. Most of the proposed works fulfilment in real conditions is very difficult. The use of virtual laboratories can be a solution of this problem. Thus, the virtual laboratory work «Examination of the law of Gay-Lussac» can be performed using the software on the portal «Physics. Virtual Laboratory – 2» [22]. Note that the order of the actions during this virtual experiment coincides with the real one, which makes it possible to compare the obtained results (real and virtual). The purpose of this work is to observe the isobar process and verify the validity of the law of Gay-Lussac. The right part of the window shows the equipment necessary for the work: a glass tube, a cylindrical vessel (on the left), a glass of water at room temperature (on the right), plasticine, a thermometer, a ruler, an alcohol lamp. The thermometer in the initial position shows the ambient temperature. All devices are used in turn, using the «click» of the left button of the computer mouse.

Calculations of the experiment results including absolute and relative errors are carried out using the calculator located on the right side of the screen; they are entered into the table located at the bottom of the web page. At the end of the lab, pupils are asked to give answers to control questions.

The use of virtual simulations at the stage of knowledge control allows the teacher to determine the degree of the formation of pupil competence more exactly. For example, when studying an important fundamental notion of «intermolecular interaction», pupils can be invited to perform a test task using the simulation «Basic principles of Molecular-Kinetic theory » of Physics Education Technology (Fig. 7) [21].

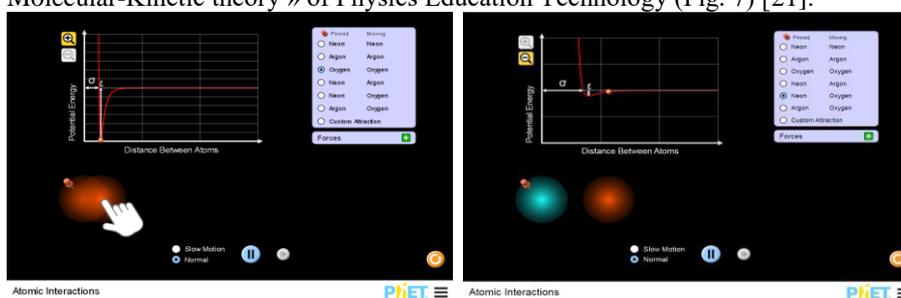


Fig. 7. Tasks for the topic «Basic principles of Molecular-Kinetic theory» [21]

Pupils are offered to work with the simulation and answer the test questions. It is possible to pass the test both on a printed form and in an interactive mode using the «LearningApps» (<https://learningapps.org/>), «Kahhot!» (<https://kahoot.com/>), «Online Test Pad» (<https://onlinetestpad.com/ua>), «Master test» (<http://master-test.net/>).

Of course, a virtual experiment cannot completely replace the real one; however, the results of our research indicate that the virtual experiment allows:

- to show clearly many physics phenomena and certain experiments that cannot be reproduced in real life;

- to demonstrate those subtleties of the process, which are invisible when performing laboratory work in real life;
- to highlight the main thing and to remove the secondary factors of influence during the experiment;
- to establish certain regularities of occurrence of phenomena in special conditions, which cannot be created in reality;
- to repeat the research many times with varying parameters;
- to change in the wide range the initial parameters and conditions of the research;
- to simulate situations impossible in real conditions, etc.

3 Conclusions and Prospects for Further Research

Summarizing the abovementioned, we can say that the formation of a scientific picture of the world for pupils is a complex process of perception of the original philosophical ideas and principles of science, understanding of the basic theories, the mastering of fundamental concepts, and the ability to apply research methods during further education. An important role in the process is played by natural sciences; physics takes the main place among them.

The definition of virtual educational physics experiment as a kind of educational physics experiment acting as a means of demonstration or simulation of physics processes and phenomena with the help of a computer is substantiated in the research. Didactic importance of VEPE is the following: it is simultaneously a method, a form, and a means of study. It is shown that the use of mathematical models of phenomena and processes is particularly important in the process of formation of initial competences in physics at the level of understanding of fundamental laws, phenomena, and processes in the material world.

The peculiarities of methodology of usage of video clips (updating of knowledge, explanation of new material, independent work of pupils), virtual animations (demonstration of complex experiments), interactive models (establishing a direct connection between the physics phenomenon and the law), virtual laboratory works (fulfilment of learning research) are considered on the example of VEPE application during the study of molecular physics. The elements of the method of usage of virtual simulations with test questions for determination of the degree of formation of pupils' subject competence are worked out.

It is shown that VEPE has powerful didactic capabilities as a means of constructing the world scientific picture at the level of awareness of physics and general scientific concepts, principles, and laws. It is concluded that its special function is the formation of the sensory-imaged component of the scientific worldview for development of imagination of physics objects and their properties by visualization of the model of a real phenomenon. Such a feature of the VEPE is significant at the initial stage of the formation of elements of the scientific worldview.

Note that the features of VEPE as an educational tool, in particular, for the action with idealized images, determines its interconnected use with a real physics experiment

where external influences and perturbing factors can be detected that lead to a «distortion» of the theory. This approach will form critical thinking and research skills during solving real problems of the surrounding world. Therefore, the search for innovative approaches to the integration of VEPE and real-life research, which will promote both the visibility and accessibility of material perception, as well as the development of creative abilities and various forms of thinking, remains relevant. An important role in the construction of appropriate methodological systems belongs to the synergetic approach.

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