The value of a complex physical experiment virtualization in the strategy of improving the educational process

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Abstract
It has now been established that the modern educational process is becoming more effective when using interactive, multimedia-rich educational resources that provide active teaching methods. The best way to meet these requirements are educational resources and virtual reality systems. An example of such electronic resources is virtual laboratory work, which can simulate the behavior of real-world objects in a computer-based educational environment and help students learn new knowledge and skills. This is relevant and already mandatory in the study of scientific and natural disciplines, such as chemistry, physics, mathematics, computer science and their combinations. Virtual laboratories contribute to increasing visibility, interactivity, as well as the formation of students’ cognitive and creative activity. In this regard, the development of a virtual model of a physical experiment on laboratory equipment that has a real analogue was the goal of this work. The paper presents data on the creation of the experimental setup interface developed in the laboratory of a pulsed plasma accelerator of Al-Farabi Kazakh National University, called the vacuum-arc accelerator (hereinafter VAA-1). At this installation, experiments are carried out to obtain coatings from various materials on a metal base from structural materials in order to create a protective and multifunctional layer on its surface.

1. Introduction
Currently, much attention is paid to the problem of integrating new information technologies into the educational process. The use of new information technologies, multimedia products orients the methodology of teaching physics in the direction of increasing the effectiveness of training, simplifying the teacher’s work. One of the problems in teaching physics is the complexity of perception, and, accordingly, understanding of many physical phenomena and processes by students. The consequences of this may be a lack of understanding and inability to see the problem and its solution as a whole. There are also nuances associated with psychological perception, the ability to concentrate, the difference in the level of students’ cognitive ability, including within the same learning group. This requires a differential approach to learning, which is relevant, especially for the second level of education (universities), and is actively used at present in the education system [1]. In the traditional forms of the educational process in a university, this possibility is realized in the course of laboratory work, where the study of an object, phenomenon, process is provided through direct contact, participation in an experiment, creation of an abstract model or visual demonstration. This provides additional opportunities for understanding, analysis and the correct execution of the work.

¹ This work was supported by project of MES RK №AP05130108
Physics is one of the first sciences in which an experiment was used to gain new knowledge and test scientific theories. To date, in the traditional curriculum of the university, for the study of physical phenomena and experimental verification of basic theories, laboratory physical workshops have been used for general and special courses in various branches of physics [5]. But the constant lack of sufficient equipment limited the ability of students to access the most interesting and unique equipment, technical facilities, scientific and technological experiments, which are sometimes of the greatest interest and stimulate the acquisition of knowledge.

Conducting research and development of experimental facilities in scientific departments, institutes or laboratories of the open type of the university allows to implement and improve the physics education program at the university. The most effective solution to the problem of understanding, increasing interest in studying any scientific problem or task is to introduce a new type of experiment into the educational process - a virtual physical experiment. One of the goals of creating a virtual physical experiment and a virtual laboratory as a whole is the desire for a comprehensive visualization of the studied processes, and one of the main tasks is to provide the student with the opportunity to prepare for the most complete perception and understanding of their essence [3].

In this paper, the use of virtual visualization as a means of increasing the cognitive activity of students is proposed. When conducting laboratory work, a preliminary understanding of the physical foundations of a given phenomenon or process, the purpose of the work will significantly reduce the time to study the phenomenon or process and qualitatively complete the task. The creation of computer virtualization in this case is the best solution to this problem. In addition, computer virtualization allows students to implement those experiments that for one reason or another are difficult or not reproducible in these laboratory conditions. This may be due to the study of micro- or macrocosm objects. The task is also complicated in the case of studying physical phenomena and processes requiring heating or working with radiation. Safety is an important advantage of using the virtual experiments in cases where the experiment is associated, for example, with high voltages or chemically active substances.

Virtual laboratory work is one of the progressively developing types of laboratory classes, the essence of which is to replace real laboratory research with mathematical modeling of the studied physical processes, but with elements of virtual interaction studying with laboratory equipment [4]. Depending on the used software tool environment, you can create an adequate illusion of working with real objects. The term “virtual laboratory” in this case refers to a set of computer information that could replace the actual implementation of the laboratory work under consideration in a physically existing laboratory unit during the educational process. It will also provide the student with the opportunity to activate independent work with information sources.

In this work, for laboratory research, the main emphasis was placed on the equipment virtualization, the technical equipment of which requires preliminary training, special knowledge and practical skills for access to work on it. In addition, costly parts and the individual components life are often included in laboratory equipment, and installations are generally limited due to wear and tear. The ability to simulate the experimental setup operation, its virtual detailing will help to better understand the principles of work, the physical basis of the processes taking place in it [5]. Computer visualization also in many cases allows you to implement conditions that are fundamentally impossible to implement in real laboratory conditions.

2. The rationale for conducting a virtual physical experiment at VAA-1
This paper represents the results of introducing virtualization elements into a physical plasma experiment both for understanding and getting acquainted with the experimental plasma setup device - a vacuum-arc accelerator (VAA-1, Figure 1), and for explaining the processes associated with obtaining a gas-discharge plasma [6]. VAA-1 was developed in the laboratory of the Pulse plasma accelerator KazNU named after Al-Farabi. The operation of this installation is associated with the content of several special training courses in plasma physics and accelerator technology for students of technical specialties, since gas-discharge plasma currently has a wide range of studies and applications. At the
VAA-1 installation, experiments are carried out to obtain various functional coatings by the vacuum-arc spraying method.

Figure 1. Appearance of the VAA-1

Vacuum-arc coating is a method of physical evaporation and deposition of thin films in a vacuum, in which material flows from the cathode spot of a vacuum arc are generated and, subsequently, they condense on the substrate. For the process of ionized material particles condensation, the temperature of the substrates should be lower, which is ensured by an autonomous cooling system of the outer surface of the vacuum chamber and electric arc evaporators, i.e. The so-called cold plasma is formed on the VAA-1 unit [7]. This is due to the plasma formation mechanism in this setup. For example, in the VAA, an electric arc is used to form a plasma clot. The ignition of the arc discharge is provided by passing an ignition pulse with an amplitude of ~ 10 kV. The operation of the vacuum arc accelerator is based on erosive destruction of the cathode’s surface layer, made of evaporated material, under the influence of burning an electric arc arising in the discharge gap between the cathode and the anode. Particles of the evaporated material are deposited in the form of a film (coating) on the surface of the sample studied.

Figure 2 shows photographs of the microstructure of the material’s surface before and after the experiments in VAA-1. The photographs were taken with a Quanta 200i 3D scanning electron microscope, briefly SEM.

The appearance of an electric arc in a vacuum is unique in that the entire rather high (100 A or more) discharge current is concentrated on the cathode in microscopic (~ 10 μm) cathode spots (CP), in which the current density and power, concentration and pressure of the resulting plasma can reach extremely high values: 100 MA / cm² and 10⁹ W / cm³, 10⁵ cm⁻³ and 10⁻¹⁰ Pa, respectively, with a KP duration of ~ 10⁻⁷ s [7].
Figure 2. SEM image of the surface of a steel sample before (a) and after (b) deposition of copper in cold plasma VAA-1

The VAA-1 installation consists of several system units that perform certain functions. Such blocks include: a vacuum system, a storage system (capacitor bank), an electrode system, a discharge ignition system, a control and monitoring system for the installation’s operation, and measuring equipment. Accordingly, each block consists of separate elements, some of which are not directly accessible. Thus, the coordination of such a complex plasma installation’s work as a whole and the quality of conducting an equally complex experiment depend on the qualifications of the working staff. To obtain qualification admission, a minimum master’s degree and at least three years of experience working on such equipment are required. It should be noted that the specificity of the installation parameters presupposes the availability of skills for working with high voltage and requires special safety measures, the simplest of which is the performance of any work on the installation with the obligatory presence of an engineering worker or responsible work manager.

In such cases, mastering the operation of this facility would be easier with the preliminary passage of students through training on a virtual prototype of the experimental facility VAA-1. The development of such a layout would allow for a clearer visual representation of the physical principles of operation of both individual units and the entire installation. In addition, the introduction of virtualization elements into a real physical experiment would optimize feedback and facilitate mutual understanding between the teacher and the student, which, naturally, would help to increase the efficiency of the educational process. A plus in this case will be the fact that while a certain real experiment can be carried out only once, the virtual model can be used again and again, without limiting the time and place of training and additional financial costs.

Therefore, the aim of this work was to create a computer virtualization of the VAA-1. Due to the complexity of the implementation of the task, it was decided to break it into the following stages:

- development of a virtual 3D layout of the VAA-1 design, its internal content;
- analyzing the progress of the experiment and create a phased computer 3D model of the physical processes occurring in VAA-1;
- creating a dynamic visualization of this phenomenon using the appropriate programming language and the experimental results obtained;
- developing virtual laboratory work and user interface;
- to develop a methodology for conducting a training experiment using this interactive laboratory equipment;
- approbation of virtual laboratory work.

The effectiveness of using computer models for both physical processes and simulating the work of a complex experimental setup is determined by their readiness for innovation, individualization and
training differentiation. Such computer visualization will fully ensure the possibility of independent work with the virtual elements of the installation at various stages of the experiment. Of particular relevance is the creation of such a software interface that would allow the full implementation of both educational and scientific experiments, i.e. for solving applied problems. This work has developed a 3D model of a vacuum-arc installation and a 3D model of the plasma processing of material in VAA-1.

3. Development of computer virtualization VAA-1
To implement this task, it was proposed to use the 3D MAX computer program. The use of well-known computer programs or software products can find direct application in the educational process and scientific research.

3D Studio Max is a professional software package created by Autodesk for the full-fledged work with 3D-graphics, containing powerful tools not only for direct three-dimensional modeling, but also for creating high-quality animation [8].

Among the mass of various products related to 3D modeling, 3ds Max is a program that has captured a significant market share. Autodesk 3D Studio Max is a full-featured and professional system for working with 3D graphics and animation, which includes a complete list of tools necessary for building three-dimensional objects: modeling, particle system, physics, rendering, additional plug-ins. For example, thanks to the MassFX application, you can simulate the behavior of even such simple household items as hair, a tablecloth, water, taking into account the physical forces acting on them, including gravity. In a word, the possibilities to control physical processes in 3ds Max are endless. Behavior models can be presented in the form of scripts or plug-ins written in C++.

In the presented work, the 3D model of the VDU-1 installation includes the creation of an interface — a platform for the installation itself and its internal contents, as shown in Figure 4.

Figure 3. The working chamber and the vacuum system unit in the context of the virtual layout VAA-1 in 3Ds Max version

The standard 3ds Max software package also includes a visualization subsystem that allows to achieve fairly realistic effects of the plasma processing process, which is important for monitoring the proposed plasma experiment, since access to some parts of the experimental setup at the time of its operation is
limited or even impossible. Figures 4, 5, 6 show various details of both the installation itself and the process of applying a functional coating in an arc discharge plasma under real conditions and in an analog of computer virtualization.

Figure 4. - Appearance of the VAA-1 installation and sample of material: a - an experiment with an arc discharge in vacuum, b - the location of the sample in the working chamber of the VAA-1, c - the appearance of the steel sample after processing on the VAA

A real experiment on processing a steel substrate material in vacuum was carried out with the following parameters: pressure \( p = 4.5 \times 10^{-3} \) Pa, charge voltage \( U = 168 \) V, processing time \( t = 1800 \) sec. As already mentioned, Figures 6 and 7 show virtual analogues of the installation details and the vacuum deposition process obtained on 3ds Max.

Figure 5. Experiment at VAA-1 in 3D format: a - 3D model of a vacuum-arc installation VAA-1, b - design of the electrode system, c - virtualization of the experiment at VAA-1
The results of a plasma experiment obtained using virtualization can be used both to study the physics of plasma processes and to optimize the operation of the setup itself, which will undoubtedly contribute to a strategy for improving the students training in technical specialties.

4. Conclusions
As a result of the research, the following data were obtained:

- Virtual laboratories allow not only modeling objects and processes of the surrounding world, but also organizing access to real laboratory and scientific equipment, as was suggested in this work with the VAA-1 installation.
- In this it was shown that the computer virtualization of VAA-1 using Autodesk 3D Studio Max allows you to study not only the operating principles and design of the installation, but also the appearance and operation of its system units. This will naturally help in the training of qualified specialists, in the future serving the VAA-1 and students performing diploma work on it.
- It should be borne in mind that physics studies natural phenomena, and not virtual reality. Therefore, physical models are always an approximation to reality. And computer experiments cannot be a full-fledged replacement for real ones, but can complement them, help in their theoretical understanding and analysis.

Conducting, developing and controlling a physical experiment is a very complex process that requires a deep understanding of the phenomena occurring in the experiment and practical skills in working with experimental equipment. Therefore, the virtual elements introduction into the experiment is relevant in the present educational process and will contribute to better assimilation of the studied material by students [9]. In addition, this will reduce the training time on laboratory equipment.

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