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The Use of Digital Laboratory Work in Quantum Physics in the Process of Learning Physics Teachers

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Abstract

In the process of studying physics to solve the tasks of forming the foundations of a scientific worldview, the development of intellectual abilities and cognitive interests of students, the main attention should be paid not to transferring the amount of ready knowledge, but to acquaintance with the methods of scientific knowledge of the surrounding world, the formulation of problems that require students to independently work to resolve them. The relevance of the study of this problem is due to the fact that one of the difficult sections for training physics is the section "Quantum Physics". To achieve the best learning outcomes in this section, it is advisable to supplement the existing physical laboratory workshop with virtual interactive computer laboratory works that simulate those physical processes whose study is difficult or impossible with existing laboratory equipment, which allows a better understanding of the essence of such processes. The purpose of the work is to develop and test a digital laboratory workshop “Quantum Physics”, which allows to increase the level of understanding of the essence of physical processes considered in quantum physics and gives a chance to the development of professional competencies of a future physics teacher. To achieve this goal, the authors used the following research methods: theoretical analysis of the state of the problem based on the study of methodological, didactic, psychological and specialized literature, dissertation research on this problem; materials of conferences on the use of digital technologies in physical education, regulatory documents that determine the structure and content of professional training of a physics teacher, the study and generalization of pedagogical experience; computer modeling of physical processes, observation, conversation, questioning, interviewing, conducting a pedagogical experiment. The digital laboratory workshop “Quantum Physics” direct to create a connection between the mathematical formalism of quantum physics and its specific practical manifestations. The focus of the digital laboratory workshop “Quantum Physics” is on the physical side of the issues addressed. The results of the testing, observation and conversation during the submission of the report on the implementation of laboratory work showed that the introduction of the digital laboratory workshop "Quantum Physics" in the educational process allows you to increase the level of understanding of the essence of the physical processes considered in quantum physics.

Keywords: digital laboratory workshop, quantum physics, independent work, Research activities, computer experiment, virtual experiment, digital experiment, physics training, physics teacher, physical processes.

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Introduction

Modern society need forming of a new model of person, capable to actively and creatively acquire knowledge, quickly and adequately respond to changing situations, anticipate developments and work with modern information tools.

Physics as a science is the basis of scientific and technological progress. The importance of physical knowledge and the role of physics are constantly growing and have an impact on the economic and cultural development of society. In the course of physics, phenomena occurring in nature are studied, and the clarification of the essence of these phenomena is based on the basic principles of philosophy. The laws discovered by physicists in the study of many phenomena serve their use in favor of humanity, are the basis of technological processes of production, are widespread use in the use of mineral resources for the needs of mankind and for their study. Physical processes play an important role in biology, geography, and agriculture. Knowledge of physical phenomena is necessary for workers in many professions. This allows us to characterize physics as the basis of many professions and to raise interest in various professions during its study. Considering physics as an integral part of general education, it should be noted its humanitarian significance, which consists in equipping the student with scientific methods of cognition and is an important factor in the upbringing and development of a full-fledged personality. In accordance with the new paradigm of education in the study of physics, the main attention should be paid not to transferring the amount of ready-made knowledge, but to acquaintance with the methods of scientific knowledge of the surrounding world, the formulation of problems that require students to independently work to resolve them, which will contribute to the formation of the foundations of a scientific worldview, the development of intellectual abilities and cognitive interests of students.

An experiment is an extremely powerful tool in teaching physics. Without diminishing the importance of theoretical learning, we can confidently say that the use of physical experiments in learning meets the fundamental principles of learning, namely mindfulness and activity, visibility, systematicity and consistency, strength of knowledge, accessibility, and most importantly, scientific knowledge and connection of theory with practice. Performing experiments forms intellectual and practical experimental skills, which include, on the one hand, the ability to determine the purpose of an experiment, put forward hypotheses, select instruments, plan an experiment, calculate errors, analyze results, draw up a progress report, and on the other hand parties to assemble the experimental setup, observe, measure, experiment. Learning through experiments is not opposed to theoretical learning, but harmoniously supplements it.

When studying certain sections of physics, different sets of competencies are formed. Mechanics and electrodynamics, being macroscopic physics, provide excellent opportunities for experimental and design activities of students, contributing to the development of creative and mental abilities. However, when studying the branches of physics related to the structure of matter, in particular, quantum physics, the possibility of conducting full-scale experiments is practically absent for various reasons: the dimensions of the systems under study are too small, the characteristic time of the experiment that does not fit into the framework of the educational process; the high cost of experimental facilities, increased safety requirements, etc. A computer experiment comes to the rescue - a virtual model of real physical experience. The well-developed interaction between the user and the machine, computer graphics and animation make it possible to widely use the virtual experiment in education. At the same time, one should not allow abuse of a computer experiment - it should be carried out only if a real experiment is impossible. It is necessary to pay attention to the formation of skills in using a digital laboratory experiment in the process of teaching physics in the course of professional and methodological training of physics teachers.

Purpose of the Study

The purpose of the work is to develop and test a digital laboratory workshop “Quantum Physics”, which allows to increase the level of understanding of the essence of physical processes considered in quantum physics and contributing to the development of professional competencies of a future physics teacher.

Literature review

Methodologists-physicists worked on the problems of educational physical experiment (Pokrovskiy, 1982; Anofrikova, 1989; Kamenetsky et al., 2002; Dick & Cabardin, 2002; Sorokin et al., 2006; Khoroshavin, 2007; Shahmayev & Pavlov, 2010) and others. The methodological basis for the use of personal computers in the system of physical experiment was solved at different times (Voronin & Chudinsky, 1999; Stepanov & Smirnov, 2010; Pospiech & Schöne, 2011; Antonova, Ospennikova & Ospennikov, 2012) and others. Particular issues of using computers in demonstration and laboratory experiments were also solved (Shamalo, 1999; Starovikov, 2002; Fiolhais & Trindade, 2003; Mayer, 2009; Ospennikova, 2011; Danilov, 2015; Akhmedova et al., 2015; Garnaeva, Nizamova, Shigapova, 2018; Garnaeva et al., 2019; Skvortsov et al., 2019) and others.

Research Methods

To achieve the goal, the authors used the following methods: studying the materials of dissertation research, didactic, psychological, methodological and specialized literature on the use of IT in teaching physics at school and university, studying and generalizing pedagogical experience; computer modeling of physical processes, observation, conversation, conducting a pedagogical experiment.

Results

Authors suggest as a method of increasing the efficiency and organizing in conducting laboratory work to use of computer technology, as well as the development of a digital version of some laboratory work. The section of quantum physics is rather complicated for students, therefore, in order to achieve the best learning result, a physical laboratory workshop on this section should be supplemented with computer simulation of those laboratory works that are difficult to perform in real mode. Computer simulation allows you to better understand the essence of the processes occurring in the experiment.

The digital laboratory workshop “Quantum Physics” aims to create a connection between the mathematical formalism of quantum physics and its specific practical manifestations. The focus of the digital laboratory workshop “Quantum Physics” is on the physical side of the issues addressed.

The digital laboratory workshop “Quantum Physics” includes the following laboratory work:

- External photo effect.

- Experimental confirmation of the nuclear model of an atom. The Rutherford Experience.

- The study of atomic spectra.

- Experimental confirmation of the wave properties of elementary particles. Diffraction of electron.

Each work is an educational-methodical complex containing a manual for the implementation of the practical part of the work, brief materials of the theoretical part of the work, an interactive computer model of a physical experiment. The experiment model developed using the MatLab software package allows you to visualize the processes that occur during the experiment and makes it possible to change the parameters that affect the course of the experiment. The model includes the possibility of both mathematical and graphical processing of experimental results. Figures 1-4 show examples of the laboratory work interface in the process of performing a practical task.

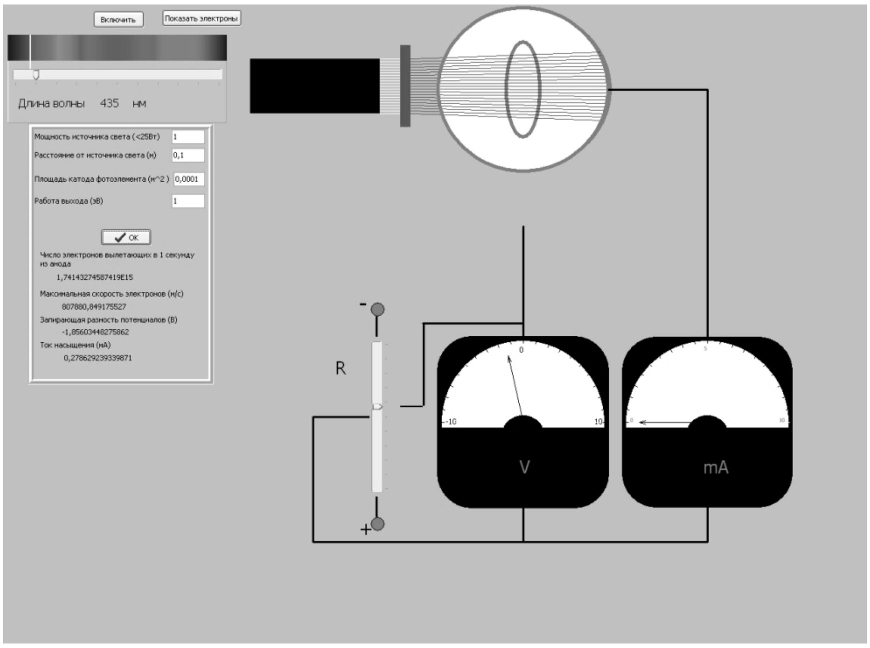

Figure 1. Laboratory work interface of “External photoelectric effect”

Figure 1 shows an interface of digital laboratory work on quantum physics “External photoelectric effect”. The aim of this work is to familiarize ourselves with an experimental study of the phenomenon of an external photoelectric effect, to confirm the laws of A. Stoletov, to construct a current-voltage characteristic and to calculate the Planck constant h.

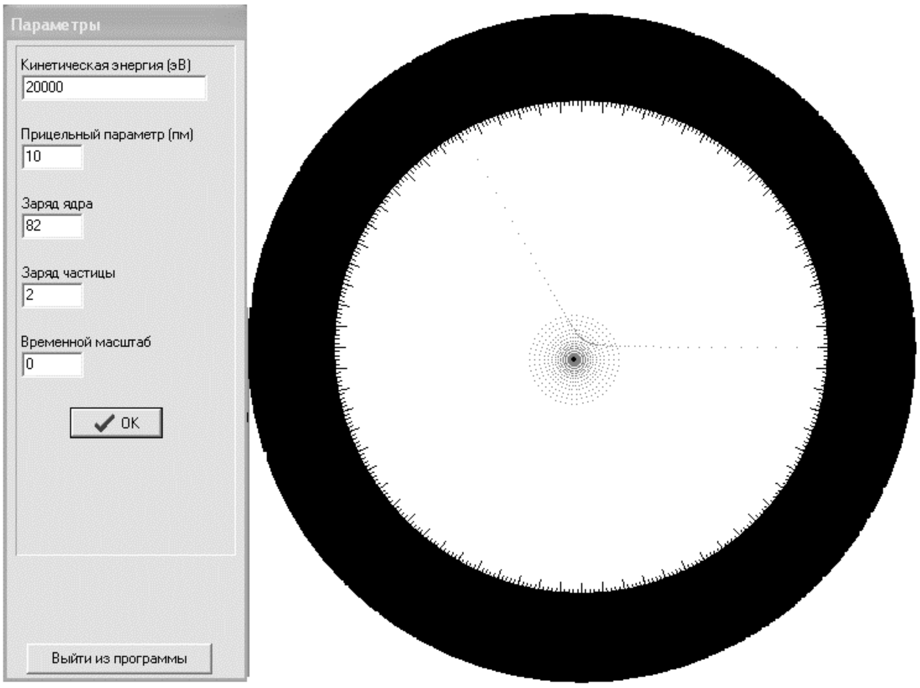

Figure 2. Laboratory work interface of “Experimental confirmation of the nuclear model of an atom. Experience of Rutherford”

Figure 2 shows an interface of digital laboratory work on quantum physics “Experimental confirmation of the nuclear model of an atom. The Rutherford Experience”. The aim of this work is to experimentally determine the dependence of the angle of deviation of an alpha particle on certain parameters (impact parameter, kinetic energy, etc.). The program clearly demonstrates the trajectory of the alpha particle and allows you to measure the angle of deviation of the alpha particle from the original path with an accuracy of tenths of a degree.

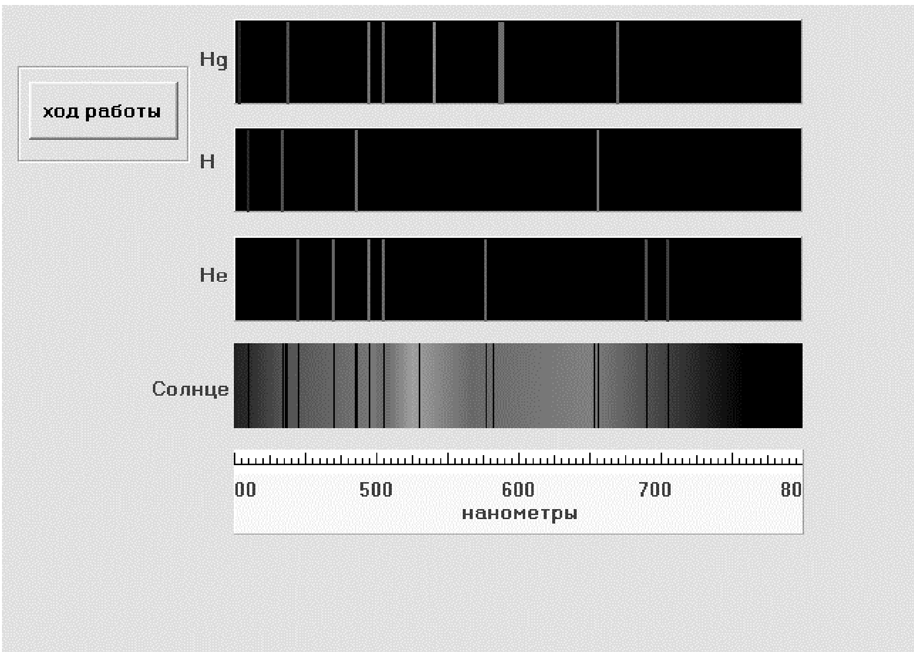

Figure 3. Laboratory work interface of “The study of atomic spectra”

Figure 3 shows an interface of the digital laboratory work on quantum physics “The study of atomic spectra”. The aim of this work is to study the emission and absorption spectra of a hydrogen, helium and mercury atom, determine the numerical value of the Planck constant h from the obtained values of the radiation energy of series of Lyman and Balmer, and also study the solar radiation spectrum.

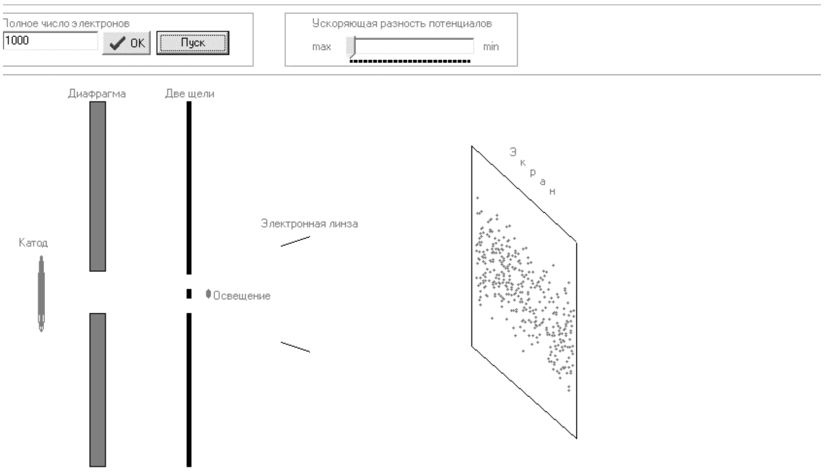

Figure 4. Laboratory work interface of “Experimental confirmation of the wave properties of elementary particles. Diffraction of electron”

Figure 4 shows an interface of a digital laboratory work on quantum physics “Experimental confirmation of the wave properties of elementary particles. Diffraction of electron”. The aim of this work is to observe the diffraction pattern of an electron beam passing through one or two slits under the condition of the presence or absence of perturbations. Determination of de Broglie wavelength of electrons and accelerating potential difference.

Discussions

The discipline “Modern quantum physics in education” is studied by undergraduate students of the scientific and pedagogical department of the Institute of Physics of KFU in the fourth year of mastering the basic educational program. In the 2018-2019 academic year, twenty eight students mastered this discipline. During the development of this course, lectures, practical and laboratory classes were conducted. Laboratory work was carried out only in the form of a full-scale experiment. Students of this group constituted the control group of the conducted pedagogical experiment on approbation. In the 2019-2020 academic year, thirty students mastered the discipline. Laboratory studies were supplemented by the work of the digital laboratory workshop “Quantum Physics”. Students of this group constituted the experimental group of the conducted pedagogical experiment on approbation. Before mastering the discipline, an entrance test was conducted with students of both groups, which made it possible to determine that the level of basic theoretical material required for mastering the discipline in the groups is the same, because the diagnostic results of both groups showed the equality of the average values with a high probability. The data of the results of the input testing correspond to validity, which are a complex characteristic of increasing the reliability of the experiment and its effectiveness.

Control after passing the laboratory workshop was carried out in the form of testing, which includes tasks of various types, which allow to identify the level of assimilation of the subject area of the course, as well as the degree of formation of methodological skills in using digital laboratory work in the process of teaching physics. The test results presented in Table 1 showed that the introduction of the digital laboratory workshop "Quantum Physics" in the educational process affects the level of understanding of the essence of the physical processes considered in quantum physics.

Statistical processing of empirical data obtained during the study was carried out using mathematical statistics methods (descriptive, inductive statistics, analysis of variance, correlation analysis) and qualitative analysis of the data obtained. The calculations were carried out using specialized computer statistical packages Microsoft Office Excel 2010, SPSS 19

Table 1. The results of single-factor analysis of variance

Comparison criteria	The average values in the control group	The average values in the experimental group	F_{em}	Relevance
Completed all tasks	35	35	2,032	0,112
Correctly completed 100% of the tasks	111,43	99,56	**4,983**	0,003
Correctly performed from 75% to 99% of tasks	35,54	30,14	**3,457**	0,018
Correctly performed from 50% to 74% of tasks	31,81	29,32	**3,555**	0,016
Correctly performed from 25% to 49% of tasks	28,19	24,14	**3,558**	0,016
Correctly performed from 1% to 24% of tasks	23,46	20,61	**5,272**	0,002

Comparison criteria	The average values in the control group	The average values in the experimental group	F_{em}	Relevance
Did not cope with all the tasks	33,58	31,09	1.328	0,267

Note: Relative differences in the results of the control testing at a given level of confidence $p \leq 0.5$ are highlighted in bold.

The results of single-factor analysis of variance allow us to conclude that there are significant differences in the results of the control test. Thus, significant differences were identified by such criteria as: correctly completed all tasks by 100%, correctly completed from 75% to 99% of tasks, correctly completed from 50% to 74% of tasks, correctly completed from 25% to 49% of tasks, correctly completed from 1% to 24% of the tasks, which indicates that the differences are significant and there is a fact of the influence of the introduction of the tested digital laboratory workshop “Quantum Physics” in groups of subjects.

Conclusion

The transition to knowledge of the microworld and megaworld reduces the possibility of implementing experimental activities of students, however, the study of these sections is possible by computer modeling of processes and phenomena occurring in these areas. Therefore, it is extremely important for a modern teacher to be able to apply the latest achievements of computer technology in teaching - including a computer experiment.

The results of the testing, observation and conversation during the submission of the report on the implementation of laboratory work showed that the introduction of the digital laboratory workshop “Quantum Physics” in the educational process allows you to increase the level of understanding of the essence of the physical processes considered in quantum physics. The level of training of a student who has mastered the digital laboratory workshop “Quantum Physics” is characterized by his ability to the following activities:

- identify significant features, establish characteristic patterns in the observation and experimental studies of physical phenomena and processes; identify known physical models in natural phenomena;
- apply known physical models to describe physical phenomena;
- build mathematical models to describe the simplest physical phenomena;
- measure basic physical quantities, indicating measurement errors;
- own a physical scientific language;
- describe physical phenomena and processes using physical scientific terminology;
- express physical information in various ways (in verbal, symbolic, analytical, mathematical, graphic, circuitry, figurative, algorithmic forms);

- give definitions of basic physical concepts and quantities;
- formulate the basic physical laws and the limits of their applicability;
- use the international system of units of measurement of physical quantities (SI) in physical calculations and the formulation of physical laws;
- own the method of estimating the order of physical quantities in their calculations;
- own the method of dimensions to identify the functional dependence of physical quantities;
- use the numerical values of fundamental physical constants to evaluate the results of simplest physical experiments;
- apply knowledge of physical theory to analyze unfamiliar physical situations:
- to argue the scientific position in the analysis of pseudoscientific, pseudoscientific and anti-scientific statements;
- name and give a verbal and circuit description of the main physical experiments;
- name the names of learned physicists who have made a significant contribution to the development of physical science;
- structure physical information using a scientific research method;
- carry out numerical calculations of physical quantities when solving physical problems and processing experimental results.

From a methodological point of view, there are various possibilities for using this digital complex of laboratory work. A set of digital laboratory works can be used in the educational process for conducting both classroom and extracurricular laboratory classes, for the organization of research workshops, educational research projects. The introduction of such laboratory work in the process of teaching physics will allow for laboratory classes in those institutions that do not have special equipment. The obvious advantage is the possibility of its use in distance learning physics.

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