Computer modelling in the physics course for IT students

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Abstract

Since today's students have a great interest in information and communication technologies (ICT), we must recognize that it contains a significant potential for development innovative approaches to learning and teaching. Organization of students' learning activities using ICT and the problem-project method can significantly enhance the feasibility of additional forms of educational processes. The author use ICT to organize the IT students' integrated problem-project activities to computer modelling of physical processes. Second-year IT students of the Technical University implement individual virtual projects. The problem-project method generates students' interest to the process of creating program products and to models of physical processes and phenomena. This complex activity stimulates processes of learning and skills development for multiple subject areas such as physics, mathematics, and programming. Usually the IT students' virtual projects are created using high-level languages C ++ or C#, and 3D editors. The students' virtual projects ultimately are software products that can be used in the e-learning environment complementing existing traditional didactic means with virtual computer experiments. The programs make it possible to do virtual experiments, observe and analyse behaviours of simulated systems and features of physical processes. In this article some virtual labs designed by our second year IT students are demonstrated. Some of virtual labs have real prototypes in laboratories and some are unique.

1 Introduction

Recent years we have seen a significant decrease of students' interest in learning physics. And in contrast a clear shift of their interest to information and communication technologies (ICT) is a fairly obvious fact [1]. Of course students' experiences with ICT provide them computer thinking and increases their future chance for choice of specialty and career growth [1]. But declining interest in physics has far-reaching consequences. Physics is a unique academic discipline that allows learning to work with model representations of reality and learn the scientific method of cognition [2]. The study of physics provides a methodological basis for students' future activities in the process of studying many other disciplines and lays the foundation for analytical thinking. Increasing of students' interest in physics is an important task of modern education.

Since today's students have a great interest in ICT, we must recognize that it contains a significant potential for developing innovative approaches to learning and teaching. The organization of students' learning activities using various opportunities of ICT and the problem-project method can significantly enhance effectiveness of additional forms of the educational process.

We use ICT to organize the students' integrated problem-project activities to computer modelling of physical processes. The second-year IT students of the Technical University plan, design and carry out individual virtual projects. The problem-project method generates the students' interest to the computer modelling of physical processes and to creation software products. This complex activity stimulates processes of learning and skills development for multiple subject areas such as physics, mathematics, and programming. Usually the IT students' virtual projects are created using high-level languages C ++ or C #, open graphics library OpenGL and 3D editors.

The IT students' virtual projects ultimately are software products that can be used in the e-learning environment complementing existing traditional didactic means. The students' programs make it possible to do virtual experiments, observe and analyze behaviors of simulated systems and features of physical processes. So, the IT students can be designers and creators of educational resources [3]. In this article some virtual labs designed by our IT students are demonstrated.

2 Computer modelling as a means for motivation in teaching and learning

Of course, the greatest effect is achieved in teaching and learning when students are directly motivated to study disciplines. But the indirect motivation can also play a significant role in transferring motives to organized training activities for the required discipline [4]. One of these motives that able to transfer students' interest to study physics is associated with a great popularity of ICT. Students' activities in the computer modelling of physical processes may be a contributing factor to the awakening of interest in physics and beyond.

For the cognition of the world we have to use simplified mathematical models of real physical phenomena. We understand any physical phenomenon if we are able to build the adequate mathematical model. Sometimes, in the framework of the adopted model it is possible to obtain an

exact or approximate analytical solution of the problem. But for the most practical problems we use numerical methods.

Numerical computations are finding their way into the curricula of more and more introductory physics courses [5-11]. A model-based view of physics provides a framework within which the computational activities may be structured so as to present to students an authentic representation of physics as a science discipline [11]. The computer modelling is a multidisciplinary field of study that encourages students to understand physics along with the computer science and applied mathematics [8].

The computer modelling includes the development of a conceptual physical model, mathematical formalization, choice of adequate methods for solving equations, software implementation of the model with the creation an interactive interface and visualization of simulated systems and processes [11, 12]. Computer models allow us to carry out various numerical experiments, which are the basis of virtual labs that can be used in training with real labs [13-15]. Modern students show a great interest both to virtual labs and to their designing.

Many undergraduate IT students of the Novosibirsk State Technical University (NSTU) already know some programming languages including even high-level languages such as C ++ or C #. This allows us to attract our IT students to the learning activities of the computer modelling of physical processes and phenomena.

3 Organization of the IT students' problem-project activity to computer modelling

What is the better way for organization of students' computer modelling activity?

The modern society's dynamics demands to use new technologies practically in all spheres of the human existence. Education is not an exception to the general trend. The modern Universities' graduates have to study the whole life, constantly adapting to new technologies and information flows. In the last decades the idea of switching from the paradigm of knowledge to the paradigm of activity is widespread. In this paradigm the main focus is shifting from the problem of mastering a particular knowledge toward the problem of development activities for extraction, processing and practical application of knowledge. The new paradigm has caused the emergence of new approaches and technologies for teaching and learning. The approach, known as Active Learning in Physics [16, 17], has been adopted in most developed countries in the physics education programs. Three methods of Active Learning are of the considerable interest in teaching and learning physics – the Research-Based Learning, the Problem Based Learning and the Project Based Learning.

The author use combination of all the three technologies for organization of the IT students' activity of the computer modelling of physical processes [14, 18, 19]. The students' activity is organized in the form of projects. The second-year IT students having programming skills design and perform virtual projects. All the students who express a desire to participate in the project activity are divided into groups of 2-4 people. The every group is given a problem for computer simulation. Some general requirements for the virtual projects are formulated and reported to the students.

All the groups perform the projects independently. The teacher only plays the role of a consultant for the students.

The process of the project activity requires decision a number of problems:

1. Selection and mathematical formalization of a model of the physical process.
2. Selection the methods for solving the model's equations (analytical or numerical).
3. Development of the flowchart of the algorithm.
4. Development of the Graphical user interface.
5. Programming
6. Virtual experiments.
7. Analysis of the virtual experiments' results.
8. Reflection.
9. Reporting.
10. Presentation.

In the process of their project activity our IT students solve a number of problems related to different subject areas - physics, mathematics, programming, design. The students use their software products for testing virtual experiments to verify the computer model performance.

One of the results of this activity is the software product - the virtual laboratory, making it possible to carry out interactive computer experiments.

4 The IT students' software products - virtual labs

As characteristic examples we demonstrate some virtual labs designed by the second-year IT students of the Faculty of Applied Mathematics and Computer Science of the NSTU. Some of the virtual labs have the real prototypes in the NSTU physical laboratories and some students' virtual labs are unique. The virtual labs are presented for different parts (not for all) of the introductory physics course of the Technical University.

4.1 VIRTUAL LAB "OBERBECK PENDULUM"

The Oberbeck pendulum is used for study the rotational laws of a rigid body. The Oberbeck pendulum is a cross-piece consisting of four rods strengthened on a cylinder under direct angle to one another. The pendulum can rotate around its horizontal axis of symmetry. The inertia moment of the Oberbeck pendulum can be changed by moving its four identical weights along the rods.

A force moment causing rotation of the pendulum is created by a tension of the thread that is winded on the sheave. The weight is attached to the free end of the thread. The moment of force can be changed by the weights of various mass or by changing the sheave of a different diameter.

The students' program simulates the Oberbeck pendulum rotation under the external force moment. The computer model is based on the dynamics laws of the mechanical motion.

The main window of the virtual lab's interface is shown on Figure 1. The Oberbeck pendulum 3D image is reproduced in the window. The interface allows changing the weights' position on the pendulum and the mass of the weight suspended on the thread. You can observe the pendulum's rotation in real time.
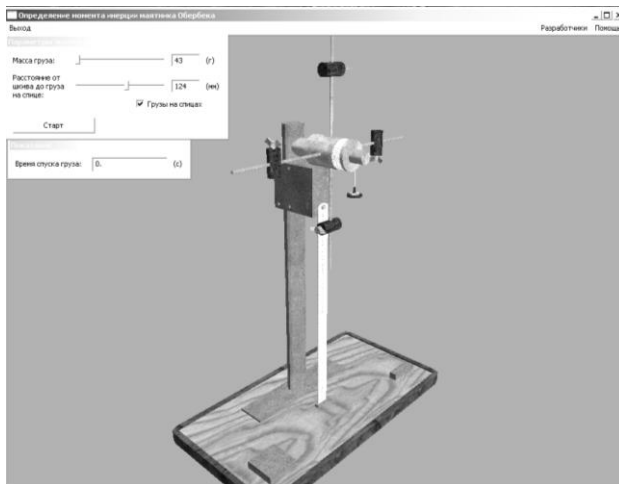
FIGURE 1 Interface of the virtual lab "Oberbeck pendulum"

Then you can measure the time and calculate a value of the moment of inertia. In addition this program simulates random measurement errors.

There are similar real labs in the NSTU laboratories. Using of the virtual lab enables our students to carry out the tentative virtual experiments at their home computers before doing the real experiments in the laboratories.

4.2 VIRTUAL LAB "OSCILLATIONS OF TWO COUPLED SPRING PENDULUMS"

Usually an analysis of the natural oscillations of coupled oscillators is presented in the part "Vibrations and waves" of the physics course [20]. Students learn the important idea of the superposition of normal vibrations (normal modes). The simplest is to harmonic oscillations of pendulums with a frequency depending on their relative phases. When the oscillations are in phase the connecting spring is not deformed, and the vibration frequency coincides with the natural frequency of the individual pendulum. In the case of out of phase the connecting spring is deformed, and the oscillation frequency is greater than the natural frequency of a single pendulum.

The normal oscillations occur in the system with the same initial deviations of the pendulums. If the initial deviations are of different size, the system beats are observed, representing a superposition of the two normal vibrations. During the beat a periodic transfer of energy from one pendulum to another and back is observed. The beat frequency is determined by the difference between the frequencies of the normal vibrations.

The students' program simulates oscillation of two coupled ideal spring pendulums. The computer model is based on the system of differential equations describing the joint motion of the spring pendulums without friction.

The main window of the virtual lab's interface is shown on Figure 2. The interface allows changing the ball's mass, the spring constant and the initial displacements of the pendulums. Depending on the initial displacements you can observe in real time the two normal modes or the beat phenomenon.
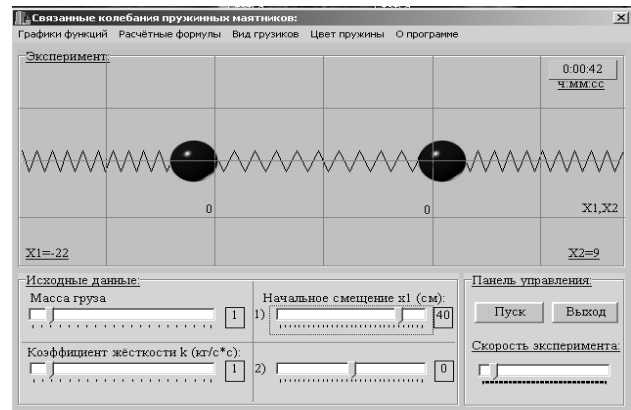

FIGURE 2 Interface of the virtual lab "Oscillations of two coupled spring pendulums"

The graphs of the pendulums' displacements and velocities are in the additional window of the interface. The curves allow us to analyze the redistribution of energy between two coupled pendulums.

This virtual lab has no real analogues in the laboratories of the NSTU. The students' software product is used as a lecture demonstration and a virtual lab.

4.3 VIRTUAL LAB "WAVES AT A BOUNDARY OF TWO JOINED STRINGS"

When any wave is falling on a boundary between two mediums there are two phenomena: wave's reflection to the first medium and passing to the other [20]. The both phenomena are determined by different reaction of the mediums to impacts associated with the wave process. The knowledge of the mediums' impedances for a particular type of waves allows determining amplitudes of transmitted and reflected waves if we know amplitudes of the incident waves [20].

The students' program simulates the wave processes at a boundary of two joined strings.

The strings are homogeneous and continuous, characterized by the same value of the tension force F, but may have different the linear density ρ. Due to various ρ the strings are characterized by two different values of the phase velocity and the impedance for the transverse harmonic waves [20]. The first leads to the different values of the wavelength on the strings, and the second - to the different reactions to the same transverse harmonic action.

The main window of the virtual lab's interface is shown on Figure 3. The two joined strings are shown in the background of the grid. The axes' scales are different in a thousand times, because the wave processes are modeled in the approximation of small transverse displacements. This means that the waves' amplitudes must be many times smaller than the wavelength.

You can watch in time the wave processes on the strings, register the real time and the transverse displacements of different parts of the strings. If on the second string there is only the transmitted wave, but on the first string the wave process is the superposition of the direct and reflected waves.

The interface allows changing the string's tension force, the linear density of the strings, the amplitude and the frequency of the incident wave.
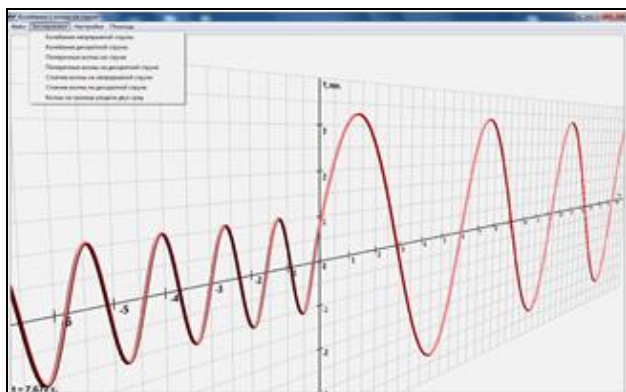
FIGURE 3 Interface of the virtual lab "Waves at a boundary of two joined strings"

The simulated processes visualization allows observing all the characteristic changes taking place due to changing the ratio of the strings densities, leading to the changes in the ratio of the impedances and the phase velocities.

This virtual lab has no real analogues in the laboratories of the NSTU. The students' software product is used as a lecture demonstration and a virtual lab.

4.4 VIRTUAL LAB "DIFFRACTION OF LIGHT"

As we know, light exhibits a dual nature! The phenomenon of diffraction evidences the wave nature of light.

All waves display the phenomena of diffraction, which arise from the superposition of waves. The waves contributing to the diffraction pattern must ultimately derive from the same single source. At each point of observation within the diffraction pattern the phase difference between component waves of the same frequency will depend on the different paths they have followed. Therefore, the resulting wave amplitude may be greater or less than that of any single component.

Diffraction is classified as Fraunhofer and Fresnel. In Fraunhofer diffraction the pattern is formed at such a distance from the diffracting system that the waves may be considered as the plane waves. A Fresnel diffraction pattern is formed so close to the diffracting system that the waves still retain their curved characteristics of the wave front [20].

One of the most interesting diffracting systems is a diffraction grating. A large number of equivalent slits forms a diffraction grating. The importance of the diffraction grating as an optical instrument lies in its ability to resolve the spectral lines of two wavelengths that are too close to be separated by the naked eye.

The students' program simulates diffraction phenomena of monochromatic light. The model is based on the Fraunhofer approximation for diffraction of plane waves on a system of parallel slits. The main window of the virtual lab's interface is shown on Figure 4.
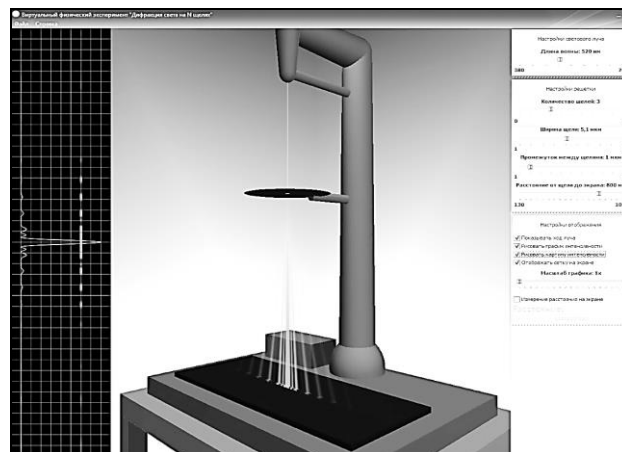

FIGURE 4 Interface of the virtual lab "Diffraction of light"

The interface allows changing the light wavelength, the width and the number of slits, the grating space, and the distance from the diffraction grating to the screen. The program allows observing and analyzing diffraction patterns.

The students realized the program tool "Interactive straightedge" using the adaptive mouse-replacement interface control functions. This tool allows measuring the characteristic distances between the maxima and minima of the diffraction pattern in the same way as in real experiments.

There are similar real labs in the laboratories of the NSTU. But in the real laboratory works we use a laser with a fixed wavelength. Only four diffraction gratings are used, and the change in distance to the screen is not provided at all. The virtual lab significantly expands possibilities of laboratory training complementing the existing real experiment "Diffraction of light" in the laboratories.

The students' software product is used as a lecture's demonstration and a virtual lab.

4.5 VIRTUAL LAB "THOMSON PARABOLA METHOD"

The charged particle motion in electric and magnetic fields is the basis of many devices and instruments of physical electronics [21]. Some of the devices are specifically designed to measure characteristics of moving charged particles. The simulation of the charged particles motion in electric and magnetic fields is an important practical task [21].

Thomson parabola mass-spectrometer is the well-known device used to determine a charge to mass ratio (q/m) of ions [21, 22].

The students' program simulates charged particle motion in electric and magnetic fields in the vacuum tube. The charged particles enter the area of the two parallel fields with the velocity vector perpendicular to the fields' directions. The electric and magnetic fields deflect particles in two perpendicular directions. The particles deviations along these two lines are related by the parabolic law [21]. The identical particles (with the same q/m) fall on the tube's screen to the points forming a parabola [21].

The students' computer model is based on equations of charge particles motion in electric and magnetic fields.

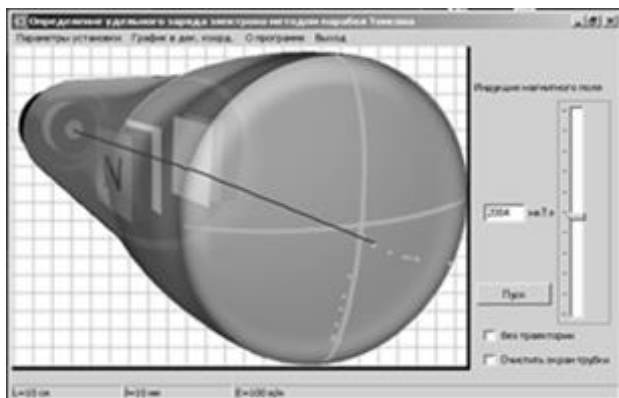The main window of the virtual lab's interface is shown on Figure 5.

FIGURE 5 Interface of the virtual lab «Thomson Parabola Method»

In the cathode-ray tube you see stylized images of the electron gun, magnetic and electrostatic deflection systems. You can observe the charged particle's movement and see the resulting trajectory.

The program interface allows changing the value of the transverse magnetic field. The length of the tube, geometric dimensions of the fields and the magnitude of the electric field are the same values.

The «Start" button allows doing the next shot from the electron gun.

In the additional interface window all the points of the electrons' hits to the tube's screen are displayed on the background grid and Cartesian axes.

This virtual lab has no real analogues in the laboratories of the NSTU. The students' software product is used as a lecture demonstration and a virtual lab.

5 Conclusions

ICT can be used to organize the IT student's integrated problem-project activities for computer modelling of physical processes.

The problem-project activity focuses on the creation of a software product, which has a certain intellectual, social and even commercial value. It makes possible to organize teaching and learning technology with the creative direction as for the learning process and for the created software products.

The creation of their own software product brings a great emotional satisfaction and stimulates further creativity of the IT students.

At the same time, it begins to appear a significant increase of the students' interest to the studied university disciplines - physics, mathematics, numerical methods and algorithms, computer graphics and programming.

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