

3D Simulation of Virtual Laboratory on Electron Microscopy

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Abstract. The interactive virtual laboratory work of electron microscopy with simulation and 3D is developed. It is shown that it could be useful learning tool for visualizing interaction methods, instruments and aids during working with unique equipment. Checklist instructions combined with the 3D graphics for execution of virtual laboratory in preparation for the real experiment with unique equipment is offered. It provides the ability of interaction with virtual laboratory objects and tools much more efficiently, as well as conducting operator's knowledge testing. A virtual lab can be efficient tool to get acquainted with the real electron microscope installation, access to which is limited. The software implementation considers the principles of visualization for deepening knowledge with the use of mathematical modeling, simulation and interactive 3D animation of complex physical processes. Developed virtual laboratory functioning is possible autonomously as well as in virtual learning environment. A three-dimensional model of the virtual installation which completely corresponds to the real installation, to make measurements using the original digitized samples is created. The possibility of comparing virtual measurement data with the results of real experiments is realized.

Keywords: 3D, Electron Microscopy, Visualizing, Virtual Laboratory, Interactivity.

1 Introduction

Computer simulations can be used as a refinement of traditional instructions for the visualization of information provided as instructional support and as computer simulation. Computer simulation can significantly enhance traditional learning, especially in the case of laboratory work.

Improvements of computer hardware and multimedia such as smart boards and mobile devices have made modeling an integral part of many science curricula. Computer simulations become available for a wide range of scientific subjects. The relevance of simulations for science education and methods of modeling to extend

traditional learning and support of the learning process is considered in [1]. Electronic computer-based virtual learning environment has the advantages that students can systematically explore hypothetical situations, interact with a simplified version of a process or system, modify the timeline of events, practice tasks, and solve problems in a realistic environment. Interactive scenarios can interact with the simulation, which distinguishes the demonstration from the simple animation. Real-time 3D imaging is widely used in medical research, especially in data collection methods, reconstruction algorithms, volume allocation methods, and clinical programs [2]. Reconstruction of magnetic resonance imaging using irregular arrays of measured signal data for reconstruction of the spatial distribution of spin density is proposed in [3].

Different technologies (microscopy, nuclear magnetic resonance, mass spectroscopy, etc.) are widely used to improve the visualization of samples in materials science, physics and chemistry. There are several virtual electron microscopy labs that use animation for visualization and mathematical models of samples [4].

Chemistry and physics are both basic and applied sciences. When teaching chemistry, high school teachers should focus on both theory and experimentation; chemical experiments play an important role in learning and serve as an ideal tool for combining theory and practice. Therefore, chemistry experiments should focus on the learning goals and development of students' laboratory skills. The influence of different forms of multimedia teaching materials on the study of chemistry, visualization of chemical compounds and file formats are described in detail in [5]. 3D demonstrations are described in [6]. Different representations of multimedia educational materials, pictures, videos and animations were used in the experimental explanations [7].

Virtual laboratories can reproduce phenomena that are difficult or impossible to observe on a real laboratory bench (such as explosive chemistry research, the fall of an object from orbit, etc.). Virtual laboratory work can also be a good tool to get acquainted with a real-world installation with limited access. Virtual laboratories can be researched on models of unique equipment (X-ray analyzers, accelerators of charged particles, equipment for space and astronomical research, etc.). The original way of teaching physics and studying simple machines, mechanisms, kinematics, dynamics, thermodynamics, electrical and optics on a computer in 3D was described in [8].

There are various virtual physical experiments of phenomena that can be compared and verified by classical formulas. In several experiments, the possibility of combined modeling of the mechanics of electricity and optics was realized. This enables students to make a clear association between the real world and its mathematical models and develop the modeling skills. The use of interactive demonstrations on electronics and data encryption in communication channels is described in [9]. The Contribution of Computer Simulation to Students' Learning of Physical Concepts (Weight and Mass) Using Modellus Software was explored in [10]. Students can create, observe and interact with analytical, analog and graphical representations of mathematical objects. Basic education has introduced many fundamental concepts of

science. Research shows that many students, and even some faculty, do not understand the scientific concepts and lab demonstrations of Earth and Space exploration and have misconceptions in these areas [11]. Although the concepts of weight and mass are central to the teaching of physics, they are still poorly understood by students. It requires the use of sequential definitions and additional 3D demonstrations. Evidence from experimental research suggests that we can improve learning by integrating computer imitations with those that are considered conceptually complex by students [12].

An overview of the PhET Physics Education Education Technology project for research, the methodology for simulation design and development of web-based interactive simulations for teaching and learning physics is discussed in [13]. It has been shown that interactive modeling can be an exciting and effective tool for the study of physics. Interactive simulations are a new way of conveying scientific ideas and engaging students in learning activities. PhET has focused on the high level of complexity, creating highly interactive, freely accessible complex simulations. Most of these simulations cover a range of physical topics, ranging from introductory material in mechanics and electricity to complex topics such as quantum mechanics, lasers, and magnetic resonance imaging. One notable characteristic of these simulations is that they blur the separation between primary and high education. PhET programs are specifically designed to engage students in active learning and to provide an environment in which they can build a solid conceptual understanding of physics through the scientific research. Simulations provide an animated, interactive and gaming environment. There are several laboratories works implemented at Unity Software [14].

2 Electron microscopy 3D Laboratory simulator

During the research we have worked on the development and application of virtual and augmented reality instruments in the electron microscopy laboratory. Electron microscopy techniques are widely used in materials science, chemistry, high technologies and interdisciplinary research. Virtual laboratory work is a useful learning tool for visualizing interaction methods, instruments and aids during working with unique equipment. 3D-scientific visualization is used to illustrate complex schemes. The developed simulator interface is completely identical to used in the real hardware.

As a virtual lab development environment, a cross-platform tool for developing two- and three-dimensional Unity 3D applications has been selected [15]. The advantages of this platform are: Unity 3d is distributed free of charge, this software has versions for Windows, Linux, MacOS, Unity-created applications support DirectX and OpenGL.

In this laboratory work, the student deals with a virtual electron microscope setup. All devices in virtual lab work replicate the appearance of real hardware. Checklist instruction, before the execution of the laboratory activity is presented on a virtual tablet. This tutorial has the form of an interactive manual that enables the student to familiarize with the installation and understand the logical basis of each step that must

be performed. The interactive tablet is also the main information center of this work, which displays all the current information that is required for the job. The use of the interactive tablet during virtual laboratory work is shown in Fig. 1.

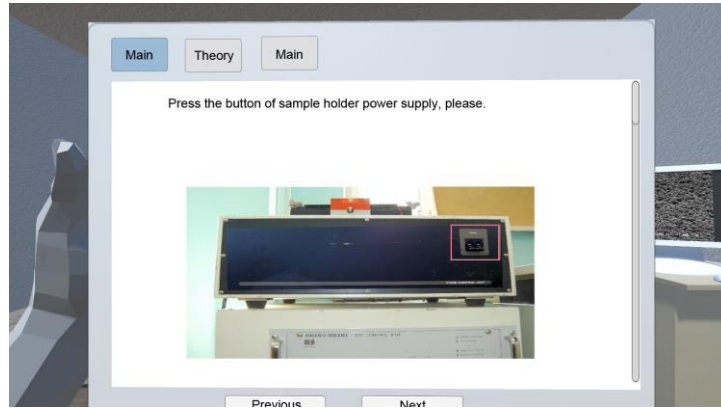


Fig. 1. The appearance of the interface on tablet. HOME tab is selected.

The “HOME” tab contains exact instructions on how the work should be performed. The student should follow the prompts and tasks of this tab from the beginning to the end of the lab work.

The Theory tab contains a theoretical part of the work that describes the physical processes that underlie the installation. After clicking on it, the student can select the desired section and get acquainted with the multimedia information provided. The “MEDIA” tab contains multimedia files that can be directly viewed by the student at any time. Folding down the tablet, the student can observe a three-dimensional model of the real installation, based on which this virtual work was created.



Fig. 2. View of the virtual laboratory.

The virtual setup view for measurement is presented in Fig. 2. The student can move through the virtual lab. The student can interact with the devices. All the available items like panels and instrument buttons are highlighted when you hover over them, which ensures interactive behaviour of the program.

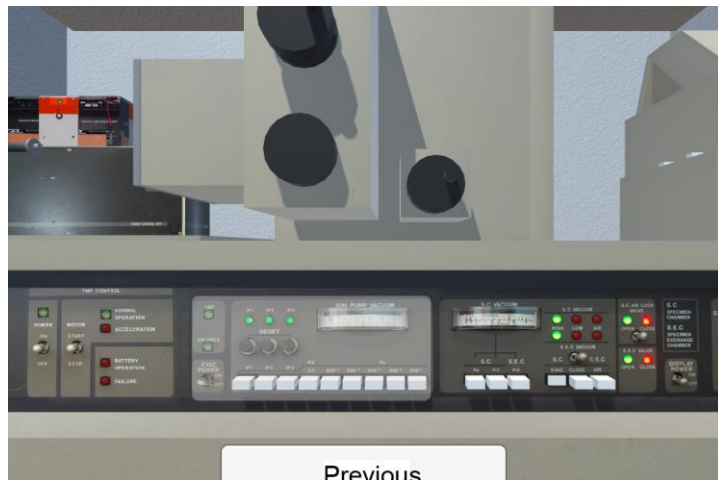


Fig. 3. Highlighted interactive elements with the possibility of zoom.

A part of an electron microscope setup with a interactive user panel is shown in Fig. 3. The student can easily zoom in on the selected panel and can go back. The lightweight travel system allows the user to navigate the lab interactively from one element to another and focus on the desired parts. The option that everything is displayed in real-time in three-dimensional space provides a seamless interaction with the device and gives a sense of presence that cannot be transmitted through a regular test and photos.



Fig. 4. Checking the vacuum level in three microscope chambers.

Figure 4 shows an image of the vacuum level control panel in electron microscope cameras. With this virtual device, the student can measure the pressure in the cells for the samples of the electron microscope. By pressing the corresponding buttons, you can see the pressure value in the cameras. By selecting the main vacuum chamber in which the electronic gun is located, and changing the sensitivity of the device, the user observes a change in the position of the arrow that shows the pressure inside the camera. Because the student works with sophisticated and unique equipment, he should clearly follow the instructions given in the laboratory work. The user of the software cannot miss the important points of the program that could cause injury or destruction of the equipment in the real world. Compliance with such sophisticated equipment is a very important point in working with real devices. Therefore, the program includes steps to ensure the safety of working with appropriate equipment. The gateway control panel is shown in Fig 5. The student must ensure that the gateway is at normal pressure before opening it. The program will not perform the next action (in this case, open the gateway) without performing preparatory actions. In addition to performing the required actions, the user must also confirm that he has completed the instruction and place the checkboxes in the appropriate place of the instruction. This kind of interactivity plays an important role in user self-validation. He cannot proceed on and make mistakes until he does everything right.

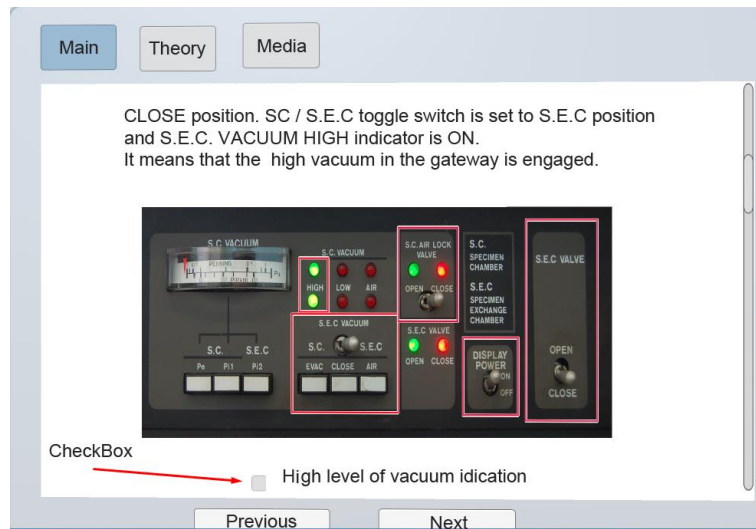


Fig. 5. Checkboxes to control the correctness of laboratory work.

The installation transparency mode is shown in Fig. 6. The student can switch to this mode. This mode gives you a clear view like the internal cameras of real electron microscope.

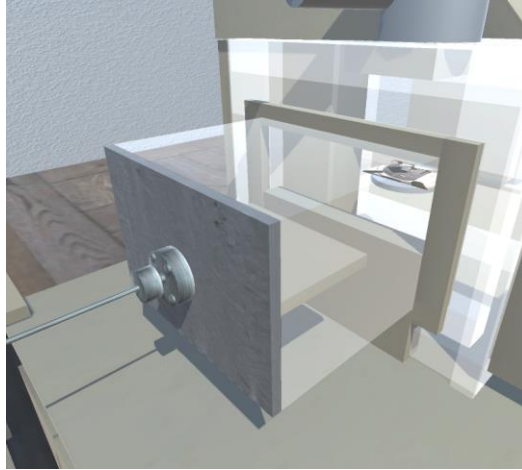


Fig. 6. Gateway opening animation.

The installation becomes transparent to demonstrate internal processes.

The main advantage of virtual laboratory work is the ability to speed up some physical processes. A simulation of the waiting of establishing vacuum in electron microscope chambers is shown in Fig. 7. The air should be pumped out of the chambers 15-30 minutes. However, the program has the option to speed up the process. Vacuum installation operation time can be reduced to a few seconds after which the user can continue operating.



Fig. 7. Simulation of waiting for the installation of the standard pump mode.



Fig. 8. Control panel of videographer.

The control panel of the videographer is shown in Fig. 8. The video screen shows a surface image obtained by an electron microscope. Just like a regular device, a virtual videographer can work with the image. Guided by the task, the student performs the necessary actions with the image. Student can adjust the brightness, contrast of the image and enlarge the highlighted area of the sample. Laboratory work uses images of real surfaces of samples. The operation of a program that measures the height of a pyramid on the surface of a sample of a solar cell is shown in Fig. 9. Due to the well-known grading on the scale of the image and the angle of inclination of the sample plate, we can accurately explore this surface. These kinds of operations are very important because they are used on industry to control product quality.

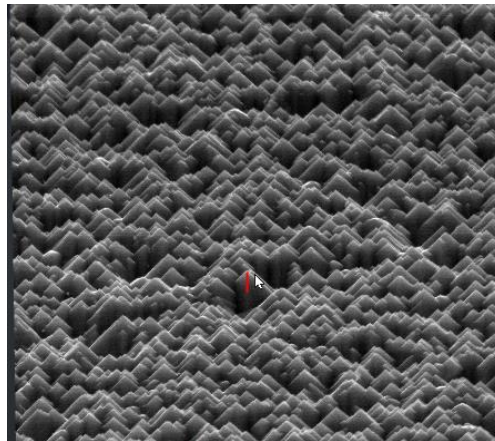


Fig. 9. Measuring the height of the pyramid on the surface of the solar cell.

At the end of the virtual laboratory activity, the user is given the opportunity to perform test tasks. An example of a test question is shown in Fig. 10. The test tasks allow student to consolidate the knowledge gained and test the depth of understanding of the physical processes used in the installation of the electron microscope.

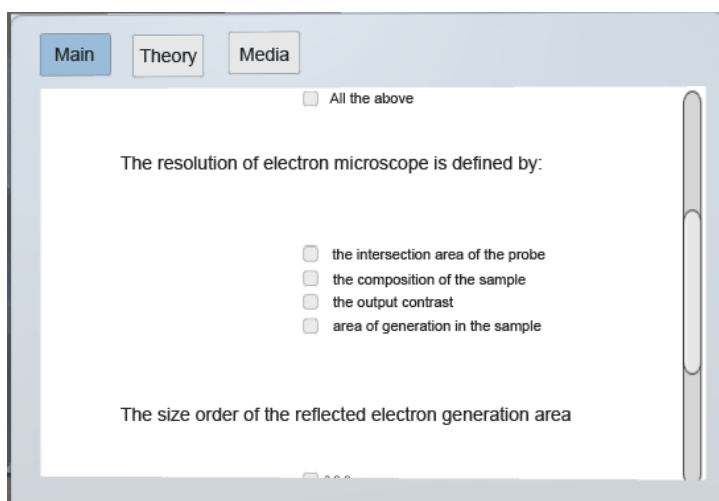


Fig. 10. Panel of the testing questions.

3 Conclusions

Laboratory work can be used in STEM disciplines: technology, engineering and mathematics, as a complement to working with high-tech equipment.

The active implementation of interactive modes and computer models in laboratory work with high-tech equipment can be a powerful means of enhancing traditional science education and a learning tool to consolidate practical skills. Using a computer simulator saves a lot of time on the professor or laboratory assistant, giving students more time instead of setting up and overseeing experimental equipment.

Computer simulation offers idealized, dynamic, and visual perceptions of physical phenomena and experiments that would be dangerous or prohibitively expensive to implement, helping students to learn the implications of modifying previous findings, evaluate ideas, gain understanding, and stimulate critical thinking. Computer simulation can be most effective when it is integrated as an additional part of the course that involves hands-on activities with sophisticated equipment.

Qualitative modeling can lead to relatively fast and very efficient study of heavy objects.

Electron microscope simulations are specifically designed to focus students' attention on the aspects that the teacher believes are most important.

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