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The Role Of Interactive Simulations And Virtual Laboratories In The Context Of Digital Education

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Abstract: This article demonstrates that the use of interactive simulations and virtual laboratories in the modern educational process deepens students' theoretical knowledge, enhances the visualization of complex physical processes, and enables the effective organization of laboratory activities.

Keywords: Virtual, simulation, interactive, electronic, experimental, research.

Introduction: In the modern educational process, interactive simulations and virtual laboratories provide opportunities to deepen students' theoretical knowledge, make complex physical phenomena more comprehensible, and effectively organize laboratory activities. In particular, conducting traditional laboratory experiments in technical and natural science subjects such as semiconductor physics may involve financial, technical, and safety challenges. Therefore, the use of virtual laboratories and interactive simulations plays an essential role as an alternative solution. These technologies allow students to visually observe complex physical processes, interactively control experiments, test various conditions, and analyze the results in real time. Moreover, conducting laboratory work in a virtual environment ensures a safe and convenient learning setting, enabling students to repeat experiments independently as many times as needed.

METHODOLOGY

Interactive simulations are software tools or online platforms that enable the visual modeling of complex physical processes, the control of variables, and the observation of outcomes in real time. Simulations serve to automate complex calculations in the study of physical laws, facilitate the safe execution of experiments, and enhance students' interest in the subject.

Interactive simulations and virtual laboratories provide opportunities in the modern educational process to deepen students' theoretical knowledge, make complex physical phenomena more comprehensible, and effectively organize laboratory activities. Particularly in technical disciplines such as semiconductor physics, conducting laboratory work in real conditions may involve financial, technical, and safety challenges. Therefore, the use of virtual laboratories and interactive simulations serves as an important alternative solution. These technologies are software tools or online platforms that enable students to visually model complex physical processes, control variables, and observe results in real time. Simulations contribute to learning physical laws by automating complex calculations, facilitating the safe execution of experiments, and increasing students' interest in the subject.[1]

Interactive simulations are software tools or online platforms that enable the visual modeling of complex physical processes, control of variables, and real-time observation of results. They help students deepen their theoretical understanding, perform experiments repeatedly, and analyze the obtained results.The main advantages of interactive simulations include the visualization of complex processes, explanation of the quantum properties of semiconductors, demonstration of electron and hole movement within a crystal lattice, and the possibility of repeated experimentation even in conditions where access to laboratory equipment is limited. They also allow students to modify experimental conditions and observe how the process evolves, providing opportunities for control and interactive manipulation.

Furthermore, interactive simulations serve as a safe and cost-effective alternative, enabling results close to real experimental outcomes without the need for expensive laboratory instruments. Interactive simulation platforms that can be used for semiconductor physics include: **PhET Interactive Simulations** — designed to simulate electrical conductivity, quantum tunneling, and properties of semiconductor materials; **Proteus and Multisim** — used for modeling electronic circuits and semiconductor devices; **MATLAB and Simulink** — for mathematical modeling of physical processes and analyzing charge carrier motion dynamics; **Silvaco TCAD and COMSOL Multiphysics** — for advanced modeling of physical processes inside semiconductor materials.[2]

RESULTS

Laboratory work supported by digital technologies plays an important role in developing students' independent research skills, fostering analytical thinking, and enhancing their ability to understand experiments and draw data-driven conclusions. From this perspective, online laboratory activities developed through the *mamatova.uz* platform integrate artificial intelligence, real laboratory modeling, and computational graphics, thereby aligning effectively with the requirements of modern digital education.[3]

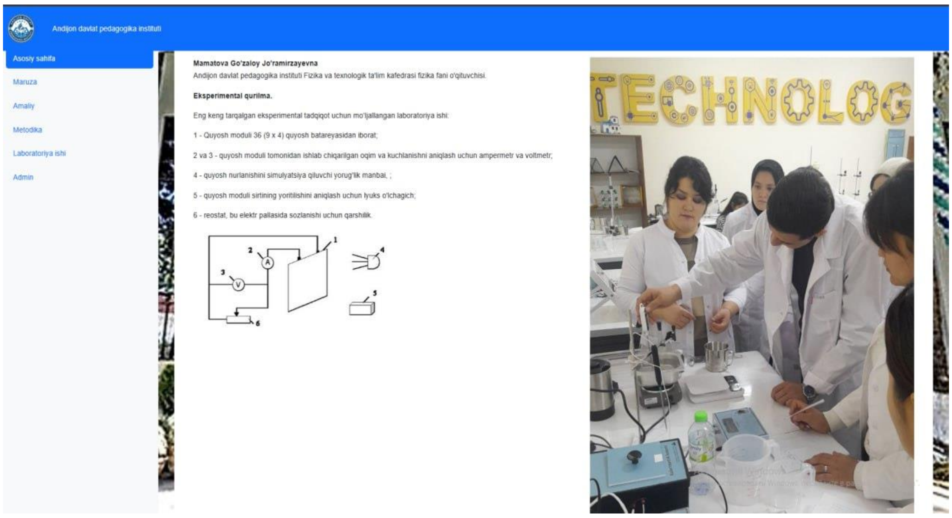

Figure 1. Interface view of the Mamatova.uz platform

Mamatova.uz is an educational platform developed by a physics instructor at Andijan State Pedagogical Institute, providing the capability to digitally simulate laboratory activities related to semiconductor physics. The platform includes interactive laboratory works, lectures, practical exercises, and methodological guidelines. The structure of the website consists of the following sections:

Lecture – theoretical learning materials

Practical – practical tasks and questions

Methodology – instructional guidelines for teachers

Laboratory Work – the main section containing interactive experiments

Admin – access panel for administrators

Figure 2. Examples of laboratory activities available on the Mamatova.uz platform

In the laboratory activity titled "Study of the Series Connection Scheme of Solar Modules" provided on the website, the following physical parameters are examined in an interactive format. In this experiment, we investigate the series connection of solar modules. To conduct the study, the user is required to input several parameters, such as:

Short-circuit current (Isc) – The maximum current that can flow through the solar panel when its terminals are shorted. Unit of measurement: ampere (A). **Voltage at maximum power (Vmp)** – The panel voltage under maximum power conditions. Unit of measurement: volt (V). **Temperature (T)** – Panel temperature expressed in degrees Celsius. Unit of measurement: °C. **Diode effect** – A coefficient that accounts for the influence of the diode on the operation of the solar panel.
Number of panels – The number of panels connected in series.

After entering the required data, the calculator displays the results in graphical form. This clearly demonstrates how different parameters influence the performance of the solar module. Subsequently, the results of series-connected solar modules under three different experimental conditions are analyzed using the graphs below. Based on these graphical results, the effects of panel quantity, diode efficiency, and temperature on PV and IV characteristics can be observed.[4]

№	Short-circuit current (Isc) (A)	Voltage at maximum power (Vmp) (V)	Temperature (T) (°C)	Diode Effect	Number of Panels	Explanation:
1	5.0	18.0	25	1.1	2	**Optimal Conditions: Room temperature and an average number of panels**
2	6.2	19.5	45	1.3	5	**High temperature, strong solar irradiation, increased number of panels**
3	4.0	17.0	15	1.2	1	**Cold conditions, fewer panels, absence of a bypass diode**

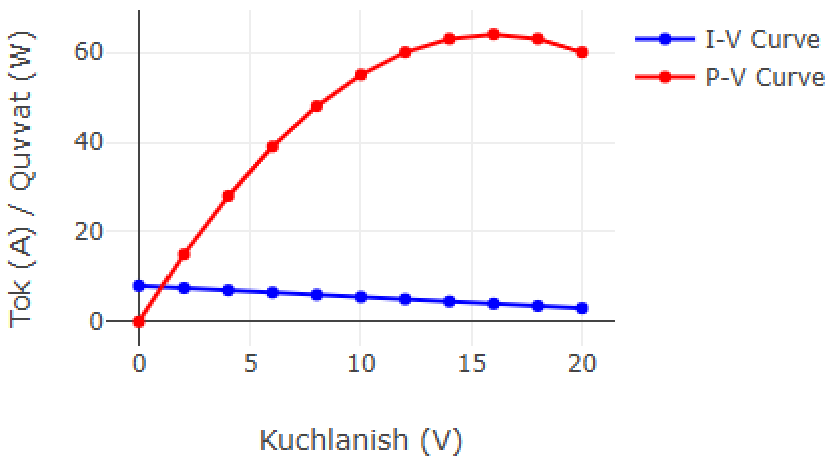

Figure 3. IV and PV characteristics obtained with 2 panels at 25°C. The graphs illustrate how the current value varies with increasing temperature. The diode effect altered the slope of the power curve.

Short-circuit current (Isc): 5.0 A
Maximum power voltage (Vmp): 12.5 V
Total voltage for series connection: 12.5 V

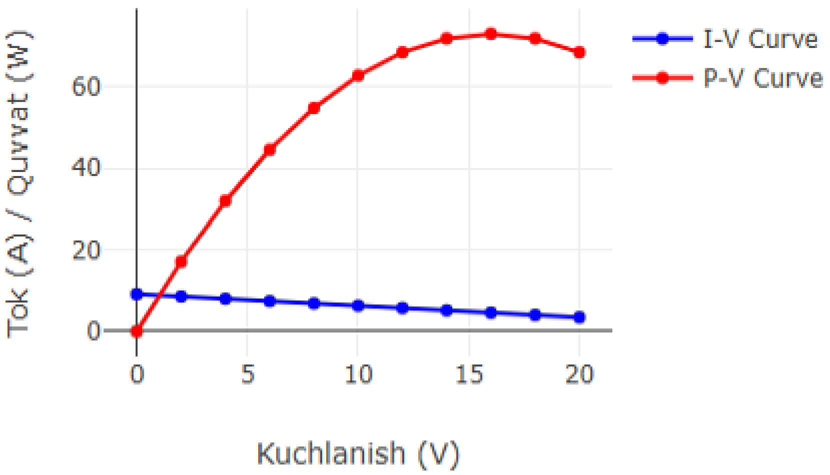

Figure 4. IV and PV characteristics obtained at 45°C with five modules connected in series. The graphs demonstrate how the increase in temperature influences the current values. The diode effect altered the slope of the power curve.

Short-circuit current (Isc): 5.704000000000001 A
Voltage at maximum power (Vmp): 11.44 V
Total voltage for series connection: 34.32 V

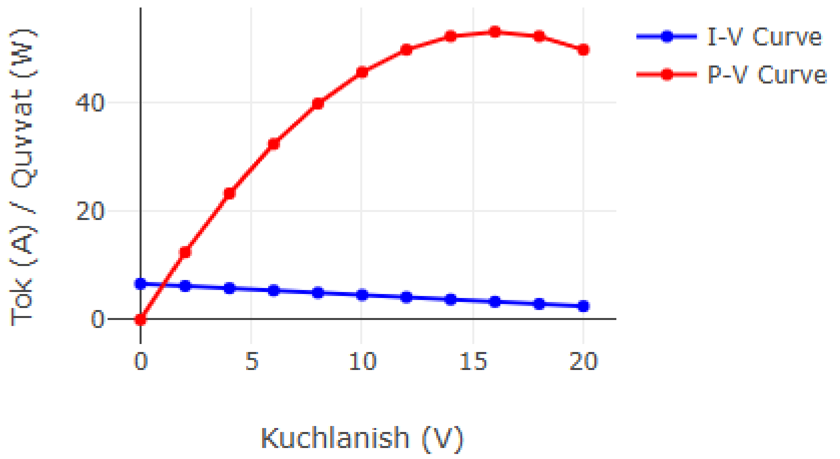

Figure 5. IV and PV characteristics obtained at 15°C with a single panel. The graphs show the variation in current with changes in temperature. The diode effect alters the slope of the power curve.

Short-circuit current (Isc): 5.704000000000001 A
Voltage at maximum power (Vmp): 11.44 V
Total voltage for series connection: 57.20 V

When analyzing the obtained graphs, although there are significant differences in the numerical values, the graphical representations appear nearly identical. This can be explained as follows:

The platform generates the graphs mainly based on two primary parameters: short-circuit current (Isc) and voltage at maximum power (Vmp).

Temperature and diode efficiency are included as input parameters; however, they are not fully integrated into the graphical algorithm, resulting in limited visual impact on the curves.

The graphs are drawn with a fixed scale (e.g., 0–25 V, 0–10 A), which makes small variations difficult to distinguish visually.

In the interface, each parameter is entered independently, and the graph is generated automatically. This not only displays the results to the student but also provides an opportunity to experiment with the underlying physical laws. By manipulating each parameter, the student can immediately observe how the resulting graph changes. This methodology ensures the integration of “experiment + analysis + visual interpretation.” Moreover, even in the absence of a real laboratory environment, learners can comprehend physical principles through virtual experimentation.[5]

The **Mamatova.uz laboratory interface** offers several pedagogical advantages:

Each parameter is accompanied by a clear explanation (pedagogical clarity);

Digital formulas and outputs are automatically calculated (reducing computational errors);

Students develop analytical thinking and experiment design skills;

It is suitable for distance learning (can be performed even at home);

It is not a closed system — learners can freely select and adjust variables (supporting independent experimentation).

This online laboratory session contributes to the development of **research competencies**, including:

independent hypothesis formulation and testing;

experiment design through adjusting various physical parameters and analyzing outcomes;

digital literacy through computation, graphical analysis, and visualization;

analytical reasoning through interpreting graphs and drawing evidence-based conclusions.

The Mamatova.uz interface is not purely virtual — real laboratory photographs, measurement instruments, and an experimental setup diagram are also provided. This familiarizes students with real equipment and circuitry, transforming virtual analysis into a preparatory step for physical experimentation and enabling foundational knowledge for real laboratory performance. For instance, the schematic representation includes an ammeter, voltmeter, solar illumination source, rheostat, solar panel angle, and measurement devices clearly displayed.[6]

Virtual laboratories are software or web-based platforms designed to simulate real laboratory environments and experiments, serving as a supplement or complete alternative to traditional laboratory activities. Their main advantages include:

Fully interactive environment — students can select, configure, and control various instruments to carry out experiments;

Simulation of real laboratory settings — allowing learners to view and practice the use of laboratory devices virtually;

Practical experimentation — enabling the study of semiconductor device operation under conditions close to real experiments;[7]

Distance accessibility — experiments can be performed from any location.

The applications of **interactive simulations and virtual laboratories in semiconductor physics education** include: modeling electron and hole motion in crystal lattices; analysis of p–n junctions, quantum tunneling, and electron-hole diffusion; demonstrating operational principles of diodes and transistors;analyzing voltage and current effects on semiconductor materials;simulating temperature-dependent electrical conductivity and carrier activation; exploring quantum phenomena, including quantum dots, tunneling effects, and fundamentals of semiconductor-based quantum computing technologies.[8][9][10]

CONCLUSION

Interactive simulations and virtual laboratories serve as innovative alternatives to traditional laboratory practices in modern education, making the experimental learning process considerably more convenient and effective for students. Their primary advantages include enabling deeper acquisition of theoretical knowledge, facilitating the visualization and comprehension of complex physical processes, reducing the dependency on physical laboratory facilities, and ensuring experiments are carried out in a safe environment. Moreover, the interactive nature of these tools fosters active student engagement in laboratory activities and enhances their research capabilities.

Thus, interactive simulations and virtual laboratories introduce new technological opportunities into contemporary educational practices and contribute to the advancement of semiconductor physics laboratory instruction. Broad integration of such technologies into the learning process can significantly strengthen students' scientific research competencies and increase their motivation toward practical laboratory work.

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