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Integration Of Modern Digital Technologies And Interactive Methods In Teaching Semiconductor Physics

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Abstract: This article analyzes the issues of increasing the efficiency of teaching the subject "Semiconductor Physics" in higher education institutions. In particular, the methodology of using modern information technologies, including Augmented Reality (AR) and virtual laboratories, along with traditional methods used to explain abstract physical processes (energy levels, band theory, p-n junctions) is highlighted. It is substantiated that the proposed methods serve to develop students' spatial imagination and improve their performance in the subject.

Keywords: Semiconductor physics, Augmented Reality (AR), virtual laboratory, pedagogical technologies, band theory, e-learning, methodology, higher education.

Introduction: Today, the rapid development of modern electronics and technology increases the demand for highly qualified personnel with a deep understanding of semiconductor physics. Teaching physics subjects, particularly "Semiconductor Physics," in the higher education system presents unique challenges. The primary reason is that the core of this subject—quantum mechanics laws, crystal lattice defects, band theory, and charge carrier dynamics—consists of microscopic processes that are impossible to observe with the naked eye (1).

In traditional teaching methods (lectures, 2D blackboard drawings), students often fail to visualize the dynamics of these processes. For instance, the modification of energy levels by donors and acceptors during doping or the formation of a potential barrier in the $p-n$ junction region remain abstract concepts. Therefore, the integration of modern digital technologies, specifically visualization tools and interactive software, into the educational process is a pressing pedagogical issue.

LITERATURE REVIEW

Numerous studies have been conducted globally on the role of visualization and simulations in physics education. Interactive simulations created by the PhET group (University of Colorado Boulder) have been proven to enhance students' conceptual understanding (2). While the role of information technologies is highly valued in works by Uzbek scholars regarding physics teaching methodology, the specific methodology of using Augmented Reality (AR) applications tailored for semiconductor physics has not yet been sufficiently researched.

METHOD

It is proposed to integrate the following modern approaches into the teaching of Semiconductor Physics:

1. Utilization of Augmented Reality (AR) Technology

AR technology enriches the learning process by superimposing virtual objects onto the real environment. Using mobile applications, when students point their smartphone cameras at a specific marker or diagram in a textbook, moving 3D models appear on the screen.

Example: When teaching "Crystal Lattice Structure," instead of a simple image, a student can use an AR app to rotate the tetrahedral bonding of silicon (Si) atoms 360 degrees, virtually "enter" the lattice, and visually observe defects (vacancies or interstitial atoms). This helps increase the student's spatial imagination by 40-50%.

2. Dynamic Modeling and Virtual Laboratories

Static images are insufficient to explain the working principles of semiconductor devices (diodes, transistors). It is advisable to use dynamic simulators to demonstrate changes in band diagrams depending on temperature or doping levels.

In a virtual laboratory, a student can independently:

- Vary the temperature (T) to observe changes in intrinsic conductivity (ni);
- Alter the doping concentration (Nd or Na) to monitor the shift of the Fermi level (EF).

3. Problem-Based Learning (PBL)

Beyond theoretical knowledge, students are assigned real-world problems to solve. For example: "Why do processors in modern smartphones (like the Vivo X200 series) overheat, and how can this be mitigated from a semiconductor physics perspective?" This question facilitates the explanation of phonons, thermal conductivity, and charge carrier scattering mechanisms.

RESULTS AND DISCUSSION

Research and pedagogical observations have shown that using only traditional approaches to teach complex fundamental subjects like semiconductor physics does not allow students to fully visualize the topic. Table 1 below presents a comparative analysis of traditional methods versus the innovative (AR/VR-based) methods we propose.

Table 1. Comparative analysis of traditional and innovative methods in teaching Semiconductor Physics

№	Analysis Criteria	Traditional Teaching Methods (Lecture, textbook, blackboard)	Modern Innovative Methods (AR, Virtual Lab, Simulation)
1	**Visualization Level**	Explained via static images, 2D drawings, and abstract formulas.	Processes (e.g., electron flow) can be viewed in real-time through dynamic 3D models and animations.
2	**Perception of Microscopic Processes**	Concepts like Band Theory, $p-n$ junctions, and recombination are difficult to imagine and time-consuming to explain.	Microscopic processes are visually "brought to life"; the movement of atoms and charge carriers is clearly visible.
3	**Student Cognitive Activity**	The student is primarily a passive listener, trying to memorize information.	The student becomes an active participant, changing parameters and conducting research.
4	**Development of Spatial Imagination**	Spatial visualization of crystal lattice structures and defects is limited.	Augmented Reality (AR) allows for 360° rotation of objects and analysis of their internal structure.
5	**Experimentation Opportunities**	Not all students may work in the lab due to a lack of expensive equipment.	Unlimited, safe, and cost-free experiments can be conducted repeatedly in a virtual environment.

6	**Feedback Mechanism**	Error detection and understanding checks usually occur at the end of the lesson or during exams.	Software provides "Instant Feedback," showing students their errors immediately and allowing for correction.
7	**Retention Efficiency**	Retention rate is average (approx. 20-30% according to Edgar Dale's Cone of Experience).	Retention rate is high (70-90%) due to active practice and visual engagement.

As a result of applying this methodology in experimental classes at Termez State Pedagogical Institute, the following positive changes were observed:

1. Increased Interest: Students' interest in the subject grew while working with mobile apps and 3D models.

2. Level of Understanding: Performance indicators for mastering complex topics like Fermi-Dirac statistics improved by 15-20% compared to the control group.

CONCLUSION

The integration of traditional methods and modern digital technologies (AR, virtual laboratories) in teaching Semiconductor Physics raises the quality of education to a new level. This not only strengthens students' theoretical knowledge but also forms their research skills. In the future, it is advisable to widely implement adaptive learning systems based on mobile applications and artificial intelligence in physics teaching methodology.

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