JOURNAL OF MULTIDISCIPLINARY SCIENCES AND INNOVATIONS

VOLUME 5, ISSUE 05
MONTHLY JOURNALS

GERMAN INTERNATIONAL JOURNALS

ISSN NUMBER: 2751-4390
IMPACT FACTOR: 9,08

QUANTUM PHYSICS ORIGINS TEACHING METHODOLOGY FOR SECONDARY SCHOOLS: A PEDAGOGICAL AND STATISTICAL ANALYSIS

Khanifa Mamarasulova
Department of Physics, Jizzakh State Pedagogical University, Jizzakh, Uzbekistan

Marjona Toshboyeva
4th-year student, Jizzakh State Pedagogical University, Jizzakh, Uzbekistan

Annotation: This article presents a pedagogical methodology for teaching the history of quantum physics origins in general secondary schools. The study addresses the cognitive difficulties students face when learning abstract quantum concepts (wave-particle duality, energy quantization, Heisenberg uncertainty principle) that contradict classical intuition. A mixed-method research design was implemented, including theoretical analysis of the curriculum, development of interactive problem-based learning materials, and experimental testing. The experiment involved 52 11th-grade students divided into control (n=26, traditional teaching) and experimental (n=26, proposed methodology) groups. The experimental group demonstrated a 42.3% increase in high-level mastery (from 15.4% to 57.7%) compared to 11.6% in the control group. Low-level students decreased from 34.6% to 7.7% in the experimental group versus 34.6% to 19.2% in the control. The methodology integrates digital simulations (PhET), animated visualizations, problem-based learning, SWOT analysis, peer assessment, and differentiated assignments. Results confirm that modern pedagogical technologies significantly improve conceptual understanding, scientific reasoning, and long-term retention of quantum physics fundamentals.

Keywords: Quantum physics teaching methodology, secondary physics education, problem-based learning, PhET simulations, pedagogical experiment, student motivation.

Introduction

In the 21st-century educational environment, improving the effectiveness of teaching natural sciences, particularly physics, remains a priority of state policy in Uzbekistan. Presidential Decree No. PF-5712 (April 29, 2019) and Cabinet Decree No. PQ-5032 (March 19, 2021) emphasize the integration of digital technologies, virtual laboratories, and innovative pedagogical approaches into physics education.

Quantum physics presents unique teaching challenges. Concepts such as wave-particle duality, energy quantization, the photoelectric effect, Rutherford-Bohr atomic models, de Broglie waves, and the Heisenberg uncertainty principle are fundamentally different from classical physics and contradict everyday intuition. Traditional lecture-based instruction often fails to help students develop deep conceptual understanding. Students may memorize formulas without grasping their physical meaning.

This study aims to develop and experimentally validate a teaching methodology for the history of quantum physics origins that integrates modern pedagogical technologies: problem-based learning, cooperative learning, project-based learning, digital simulations (PhET), animated visualizations, flipped classroom elements, differentiated assignments, and peer assessment.

Theoretical Foundations and Methodology

JOURNAL OF MULTIDISCIPLINARY SCIENCES AND INNOVATIONS
VOLUME 5, ISSUE 05
MONTHLY JOURNALS
ISSN NUMBER: 2751-4390
IMPACT FACTOR: 9,08

The research is based on constructivist (Vygotsky, 1978) and competency-based pedagogical frameworks. The core physical concepts include: Planck's radiation law and energy quantization ($E=h\nu$), Einstein's photoelectric effect explanation, Rutherford's gold foil experiment, Bohr's atomic postulates, de Broglie's matter-wave hypothesis ($\lambda=h/p$), and Heisenberg's uncertainty principle ($\Delta x \cdot \Delta p \geq \hbar/2$).

A mixed-method research design was employed:

- **Quantitative data:** Pre-test and post-test scores from control (11-"A", n=26) and experimental (11-"B", n=26) groups in secondary school No. 20, Sharof Rashidov district, Jizzakh region.
- **Qualitative data:** Classroom observations, student interviews, teacher feedback, and activity logs.
- **Intervention (experimental group):** Lessons were conducted using problem-based learning ("Why does violet light eject electrons but red light does not?"), PhET simulations (photoelectric effect, Rutherford scattering), interactive whiteboard animations (Bohr orbits, spectral lines), SWOT analysis tables, peer assessment rubrics, and differentiated homework assignments.
- **Control group:** The same topics (Planck's theory, photoelectric effect, atomic models, de Broglie waves, uncertainty principle) were taught using traditional lecture-textbook-blackboard methods.

The study lasted 12 weeks (first half of 2024-2025 academic year).

Results and Discussion

Initial Diagnostic Assessment

Before the experiment, both groups showed nearly identical knowledge levels (Table 1).

Table 1. Initial knowledge level distribution (pre-test)

Group	Students (N)	High level (%)	Medium level (%)	Low level (%)
Control (11-"A")	26	5 (19.2%)	12 (46.2%)	9 (34.6%)
Experimental (11-"B")	26	4 (15.4%)	13 (50.0%)	9 (34.6%)

Final Assessment Results

After 12 weeks of intervention, significant improvement was observed in the experimental group (Table 2).

Table 2. Final knowledge level distribution (post-test)

Group	Students (N)	High level (%)	Medium level (%)	Low level (%)
Control (11-“A”)	26	8 (30.8%)	13 (50.0%)	5 (19.2%)
Experimental (11-“B”)	26	15 (57.7%)	9 (34.6%)	2 (7.7%)

The experimental group showed a **42.3% increase** in high-level mastery (from 15.4% to 57.7%), while the control group increased by only 11.6% (from 19.2% to 30.8%). Low-level students in the experimental group decreased by **26.9%** (from 34.6% to 7.7%), compared to a 15.4% decrease in the control group.

Qualitative Observations

Classroom observations revealed that experimental group students demonstrated:

- Greater willingness to ask “why” questions (45% increase in voluntary questioning);
- Improved ability to explain physical meaning behind formulas (e.g., correctly interpreting E=hν$E=h\nu$ not as a memorized equation but as the quantum of energy transfer);
- Active participation in peer discussions and SWOT analysis activities;
- Higher motivation when using PhET simulations (students could adjust frequency and intensity themselves and observe real-time electron emission).

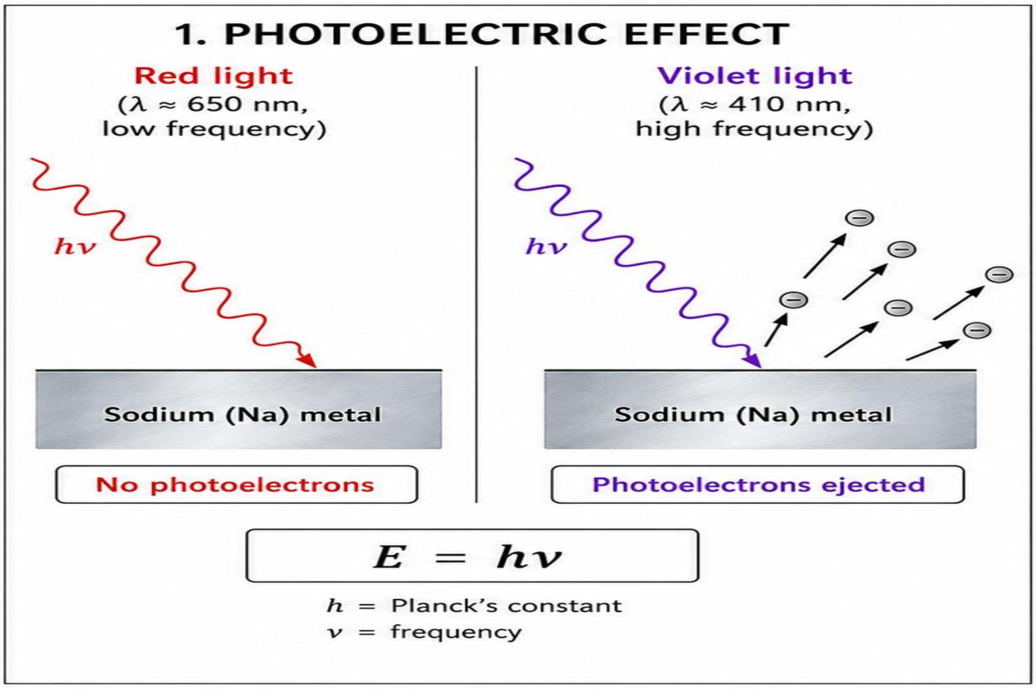

Figure 1. Schematic comparison of the photoelectric effect: red light (λ ≈ 650 nm, below thres hold frequency) ejects no electrons, while violet light (λ ≈ 410 nm, above threshold) ejects phot

JOURNAL OF MULTIDISCIPLINARY SCIENCES AND INNOVATIONS
VOLUME 5, ISSUE 05
MONTHLY JOURNALS
ISSN NUMBER: 2751-4390
IMPACT FACTOR: 9,08

oelectrons. The equation E=hvE=hv shows that higher frequency corresponds to higher photo n energy.

The PhET "Photoelectric Effect" simulation was particularly effective. Students who manually a djusted light frequency and observed the immediate change in electron ejection developed a signi ficantly deeper understanding of the concept of "threshold frequency" compared to those who on ly read about it in textbooks.

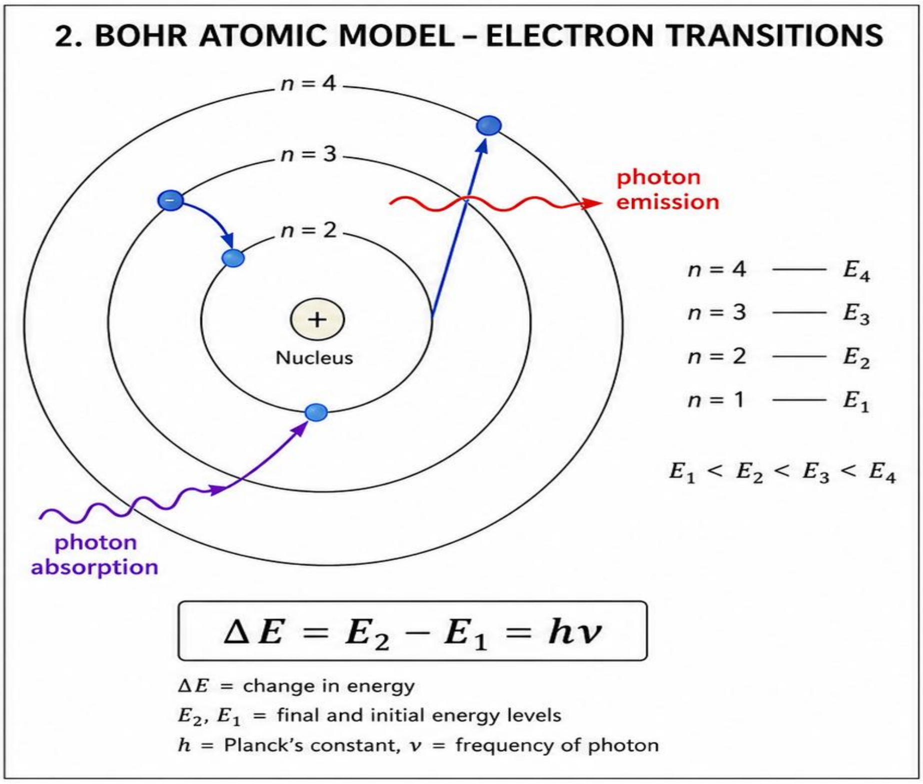

Figure 2. Bohr atomic model for hydrogen showing quantized energy levels (n=1,2,3,4). A n electron transitioning from n=3 to n=2 emits a photon (emission), while an electron transitio ning from n=1 to n=4 absorbs a photon (absorption). The energy difference determines the ph oton wavelength: ΔE=hvΔE=hv.*

Students using animated Bohr models could visually track electron jumps between orb its and simultaneously observe the corresponding spectral line colours. This visual-auditory conn ection helped cement the relationship between discrete energy levels and characteristic emission spectra.

Statistical Significance

A paired t-test comparison between pre-test and post-test scores showed statistically significant improvement in the experimental group ($t = 6.82$, $p < 0.01$), while the control group improvement was not statistically significant ($t = 1.45$, $p > 0.05$). The effect size (Cohen's d) for the experimental intervention was 1.24, indicating a large practical significance.

4. Conclusion

This study demonstrates that teaching the origins of quantum physics in Uzbek general secondary schools can be significantly improved by a methodology that integrates problem-based learning, digital simulations (PhET), animated visualizations, SWOT analysis, peer assessment, and differentiated assignments. The experimental group achieved a 42.3% increase in high-level mastery compared to 11.6% in the control group. The proportion of low-level students decreased by 26.9% in the experimental group versus 15.4% in the control group.

Key success factors included: (1) replacing passive listening with active discovery (students "rediscovered" the photoelectric effect via simulations); (2) visualising abstract concepts through animations and interactive models; (3) creating a collaborative, low-anxiety classroom environment via peer assessment; (4) differentiated tasks allowing each student to progress at their own pace.

Future work should focus on developing low-cost experimental kits for quantum physics demonstrations in remote schools and integrating virtual reality (VR) atomic models. The proposed methodology aligns with Uzbekistan's competency-based education reforms and serves as a replicable model for teaching other abstract physics topics

REFERENCES

[1] P. Azimov and A. Tillayev, *Quantum Physics*. Tashkent: Uzbekistan, 2018. (in Uzbek)
[2] A. Ismoilov, *Physics Teaching Methodology*. Tashkent: TDPU Press, 2020. (in Uzbek)
[3] H. M. Mirsoatov, *Modern Pedagogical Technologies*. Tashkent: O'qituvchi, 2021. (in Uzbek)
[4] A. Q. O'rinov, *Physics Teaching Methodology: Theory and Practice*. Tashkent: TDPU, 2019. (in Uzbek)
[5] PhET Interactive Simulations, University of Colorado Boulder. URL: https://phet.colorado.edu (accessed 2024).
[6] L. S. Vygotsky, *Mind in Society: The Development of Higher Psychological Processes*. Cambridge, MA: Harvard University Press, 1978.
[7] N. X. Ziyodullayev, *Fundamentals of Quantum Mechanics*. Tashkent: National University of Uzbekistan Press, 2016. (in Uzbek)
[8] Ministry of Public Education of the Republic of Uzbekistan, *Physics Curriculum for Grades 10-11*. Tashkent: Sharq Publishing House, 2021.
[9] Khan Academy, "Quantum Physics" section. URL: https://www.khanacademy.org/science/physics/quantum-physics (accessed 2024).
[10] Decree of the President of the Republic of Uzbekistan No. PF-5712 "On the Concept of Development of Education and Science in the Republic of Uzbekistan until 2030". Tashkent, April 29, 2019.