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Possibilities For Forming The Competence Of Visualizing Physical Processes Using Digital Models

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Annotation. This article presents a methodology for developing students' information modeling skills in the process of teaching the "Optics" section of physics within higher education. The relevance of the study is determined by the need, in the context of the digital transformation of education, for students not only to acquire theoretical knowledge but also to develop competencies in visualizing and analyzing complex physical processes using digital models.

The paper analyzes common misconceptions encountered by students when mastering concepts related to optics and outlines effective approaches for overcoming these difficulties through the use of information technologies. Furthermore, based on the CIEE model within the integrated information-educational environment of higher education institutions, methods are proposed for systematically organizing the learning process around information objects and processes.

The findings of the study indicate that the information modeling approach contributes to the enhancement of students' critical thinking skills and promotes a deeper understanding of physical phenomena. The proposed methodological recommendations are intended for students majoring in physics as well as for higher education instructors and have practical significance in the design of educational materials within a digital environment.

Keywords: higher education, optics, information modeling, digital competence, integrated learning environment, methodology, critical thinking, model CIEE.

Introduction. The digital transformation of modern higher education has fundamentally reshaped the professional training requirements for students. Today, fundamental sciences, particularly physics courses, play a vital role in building the professional competence of future specialists. Students are now expected to do more than just absorb theoretical knowledge; they must analyze complex physical phenomena, construct their mathematical models, and visualize them through information technology—effectively developing comprehensive information-modeling skills. Specifically, the "Optics" section of physics, with its high level of abstraction and heavy reliance on visualization, demands that students develop systematic information models. By its very nature, optics encompasses both geometric and wave properties, making it rich in abstract concepts. Phenomena such as light interference, diffraction, or polarization are often difficult to observe and analyze dynamically within traditional laboratory settings. At this critical juncture, the information-modeling methodology emerges as an innovative educational tool. Through information-modeling, students can construct the mathematical framework of a physical event, manipulate its parameters, and observe the real-time results on a computer screen using Python, Matlab, or virtual laboratories. This approach significantly expands the student's independent research capabilities and algorithmic thinking.

To ensure quality management in higher education, there is a growing need to establish an integrated information educational environment (CIEE) [1]. In such an environment, the educational process is modeled around specific information objects and processes, which enhances students' ability to logically structure educational material. Concurrently, framework models designed to develop the digital competencies of higher education faculty directly contribute to improving the methodologies used to teach students how to design models via information technology [2].

One of the primary obstacles in teaching optics is the presence of deep-rooted scientific misconceptions regarding light, color, and optical phenomena among students [3]. Traditional teaching methods frequently fall short in correcting these "naive" preconceptions. This is where the information-modeling methodology becomes essential: it allows students to create virtual models of physical phenomena, alter key variables, and visually analyze the outcomes. Such a framework helps students grasp the distinction between a real physical phenomenon and its model, thereby fostering critical thinking [4].

The Uzbek higher education system is actively pursuing research into integrating digital technologies within fundamental sciences, with a particular focus on computer-based modeling of physical processes [5]. Developing students' information competence by modeling complex phenomena like interference and diffraction in optics serves as a pivotal stage in preparing them for future scientific and engineering careers.

Consequently, this paper aims to develop the pedagogical and methodological foundations for enhancing students' information-modeling skills through the specific case of the optics section, while critically evaluating its overall educational effectiveness.

Literature Review. The development of information-modeling skills requires a deep integration of modern higher education's digital infrastructure with innovative pedagogical methodologies. An analysis of existing literature in this domain highlights three foundational components:

1. Structural Models of Quality Management in Education**.** According to research by A. Biloshchytskyi and colleagues, establishing an integrated information educational environment within higher education allows the training process to be modeled around specific information objects. The authors emphasize that developing the logical structure of information systems is critical to improving educational quality. The structural models introduced in this work provide a solid theoretical framework for enhancing students' capacity to process and systematically model information [1, pp. 3–4]. In particular, the Analytic Hierarchy Process (ABC/AHP) method offers significant methodological value when breaking down and modeling complex physical processes section by section [1, p. 12].

2. Addressing Misconceptions in Optics Through Target Modeling**.** S. M. Pompea and his co-authors investigated the fundamental scientific misconceptions that students frequently encounter when studying optics. Literature indicates that young learners, and even adults, often hold unscientific, "naive" notions about light and color. For instance, flawed internal models regarding the propagation of light or the mechanics of human vision present major obstacles to acquiring authentic scientific knowledge [2, pp. 1–2]. To cultivate robust information-modeling skills, this source proposes a methodology focused on visualizing these erroneous concepts and systematically replacing them with rigorous scientific models [2, p. 8].

3. Modeling Pedagogical Competences in a Digital World. Z. Kapasheva and colleagues introduced a structural framework for developing pedagogical competencies within a digitalized educational environment. Their work demonstrates that students' digital literacy and modeling proficiencies are directly dependent on the digital transformation of the learning environment itself [3, p. 3]. The model outlined in their paper provides a systematic approach for both educators and students to design learning tasks using Information and Communication Technologies (ICT). In teaching abstract fields like optics, this approach demands a thorough integration of Technological Pedagogical Content Knowledge (TPACK) [3, pp. 10–12].

Furthermore, the challenge of developing information-modeling skills remains a focal point for numerous global and domestic researchers. Within pedagogical science, the didactical potential of modeling was theoretically established in the seminal works of V. V. Davydov and N. F. Talyzina, who demonstrated that a model serves as the most effective instrument for examining an object of knowledge.

In physics education, researchers such as A. A. Ilyinsky and S. Abduvasiyev explored the methodologies of utilizing information technologies, emphasizing the distinct advantages of computer models in visualizing physical laws. Domestically, Uzbek scholars including M. Jo‘rayev, N. Shodiyev, and B. Sattarova established the methodological foundations for applying modern educational technologies to physics instruction. However, the precise step-by-step mechanisms for developing students' information-modeling skills specifically within the context of optics still require more profound investigation.

Currently, international frameworks (such as those utilized at MIT and Stanford University) place significant emphasis on learning physical models through programming within an "Inquiry-Based Learning" approach. This trend underlines the urgent need to integrate modern STEAM (Science, Technology, Engineering, Arts, and Mathematics) frameworks into our national educational system.

Complementary international and national literature further enriches this scope. The foundational theory of modeling in physics education (*Modeling Instruction*) was comprehensively established by D.

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Hestenes, who defines physics education as the construction of logical models representing physical objects and processes. Within the context of Uzbekistan's educational landscape, U. Begimqulov formulated the theoretical and methodological blueprints for digitizing pedagogical processes, offering robust models to enhance students' overall information competence.

Research Methodology. The study utilizes the systematic CIEE (Conceptualization, Implementation, Evaluation, Extension) framework to develop students' information-modeling skills. This model encompasses the entire cognitive pathway of a student, tracing their progress from abstract theoretical conceptualization to the creation and practical application of a concrete digital product.

To evaluate the effectiveness of this framework, a two-phase pedagogical experiment was conducted at Karshi State University involving second-year physics undergraduate students:

1. Diagnostic and Implementation Phase. The participant pool was divided into two distinct groups: a control group (N = 25) taught via traditional instructional methodologies, and an experimental group (N = 27) where learning activities were strictly structured around the CIEE framework.

2. Evaluation Criteria and Indicators. Students' competencies were quantitatively and qualitatively evaluated across four core performance indicators:

- Mathematical Modeling Accuracy: The precision with which students formulate mathematical frameworks representing physical phenomena;
- Software Proficiency**:** The operational execution speed and fluid adaptability within integrated development environments;
- Data Interpretation: The capacity to critically analyze, interpret, and extract scientific meaning from model-generated visual outputs;
- Project Autonomy**:** The degree of independence and self-direction demonstrated throughout the project development lifecycle.

The empirical data gathered indicates that implementing the CIEE model does not merely improve academic performance within the specific domain of optics. Rather, it serves as a driving factor in elevating the students' broader information-technological literacy and research culture. This study focuses on developing the methodological foundations for enhancing students' information-modeling skills within higher education physics, specifically focusing on the "Optics" section. The structural bedrock of this research relies on the systemic-activity approach and the learner-centered educational paradigm. This framework aims to elevate the student from a passive recipient of pre-processed information to an active researcher capable of transforming data and generating novel cognitive models.

In alignment with scientific logic, the research process was executed across four interconnected phases:

a) Theoretical-Methodological Analysis: The didactical potential and educational scope of instructional materials within the optics section were thoroughly evaluated. Diagnostic assessments were conducted to gauge the baseline level of students' existing information-modeling skills.

b) Conceptual Design of Modeling: The pedagogical conditions required to translate optical phenomena (such as interference, diffraction, and dispersion) into functional computer models were established. Here, prioritizing the logical alignment between the mathematical framework of the physical process and its corresponding computational algorithm was paramount.

c) Experimental Implementation**:** The developed methodology was put into practice among university students. Control and experimental groups were established to facilitate a comparative analysis of educational efficacy.

d) Interpretation and Generalization: The empirical data gathered was processed using mathematical-statistical methods to validate the viability and robustness of the proposed methodology.

To foster these skills systematically, a specialized methodological cluster was engineered. This cluster integrates three core structural components:

A) Cognitive-Mathematical Component. The primary objective here is to enable students to translate an observed physical phenomenon into the language of mathematical formulations. For instance, constructing integral equations for light diffraction patterns based on the Huygens-Fresnel principle serves as a benchmark task in this phase. At this stage, the student's background in differential and integral calculus integrates directly with physical reality.

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B) Algorithmic-Software Component. During this phase, the student translates the finalized mathematical model into machine-readable code. Within our methodology, the Python programming language along with its scientific libraries (NumPy, SciPy, and Matplotlib) was primarily recommended. Students acquire hands-on proficiency in utilizing loops, arrays, and functions to execute complex scientific computations.

C) Visualization and Interpretation Component. This component builds the skill to evaluate computer-generated outputs against real-world physical environments. By dynamically altering model parameters—such as adjusting the wavelength (λ) or manipulating the slit with (a)—students observe physical variations in real time. This process instills a rigorous "virtual experimentation" culture.

The research sample comprised second-year undergraduate physics students at Karshi State University. Data collection was driven by the following empirical methods:

- Pedagogical Observation: Direct observation of students interacting with computational modeling tools during regular laboratory sessions;
- Testing and Assessment: Evaluation of students' theoretical comprehension and their capacity to resolve complex, unstructured problem scenarios;
- Praximetric Methods: A qualitative and quantitative analysis of the software models, scripts, and technical reports generated by the students themselves.

To ensure the reliability and statistical significance of the research findings, *Stydent (t-test)* and the *Pirsan* (χ^2) test were utilized. The learning acquisition coefficients for both the experimental and control groups were calculated using the following formula:

$$\eta = \frac{x}{y} \cdot 100\%$$

Where x - is the mean score of the students in the experimental group, and y - is the mean score of the students in the control group.

The Young's experiment is fundamental to studying the interference phenomenon within the optics section. Developing an information model of this phenomenon enables students to parametrically control the wave nature of light.

1. Formulating the Mathematical Model**.** In the initial phase of modeling, it is essential for the student to identify the mathematical expressions representing the physical process. The resultant intensity of waves emerging from two coherent sources at an arbitrary point on the screen is determined by the following formula:

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2} cos\delta$$

Where δ - is the phase difference, which is related to the path difference Δ as follows:

$$\delta = \frac{2\pi}{\lambda}\Delta = \frac{2\pi}{\lambda} \cdot \frac{d \cdot x}{L}$$

λ - wavelength of light
d – distance between the slits
L – distance from the slits to the screen
x – coordinate measured from the center of the screen

2. Modeling Algorithm . In developing information-modeling skills, the student must algorithmicize the process step by step. Below is the logical sequence for computer visualization of Young's experiment:

Step 1: Determine input parameters (λ, *d, L).*
Step 2: Create a coordinate grid (along the x-axis) of the screen.
Step 3: Calculate the optical path difference for each point.
Step 4: Calculate the intensity distribution function *(I(x)).*
Step 5: Visualize the results in a graphic form (interference pattern).

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Software implementation and block diagram. The student demonstrates his information modeling competence by implementing this algorithm using modern programming languages (for example, Python). The following is a block diagram of this process:

Methodological recommendation: It is recommended that students ask the question "what if...?" (What-if analysis) when creating a model. For example, how will the width of the interference fringes change if the wavelength is increased? This approach increases the student's ability to physically interpret the modeling result.

1. Expected results. A student working on the basis of this methodology will acquire the following skills:

- Be able to translate a physical phenomenon into a system of mathematical equations;
- Work with physical constants and variables in a software environment;
- Analyze an abstract phenomenon (light waves) in the form of a visual graphic model.

The methodology we propose involves not only the use of a computer, but also the combination of "Problem-Based Learning" and "Project-Based Learning" (PBL) technologies. Students are given open-ended project tasks such as "Creating a model for eliminating aberrations in optical systems." In this process, the student independently works with literature, builds a model, tests it and defends the result.

This methodological approach proves that students' information modeling skills are not a process that develops spontaneously, but a cognitive activity that is systematically controlled and provided with pedagogical components.

Research results. The research results show that the introduction of the “Optics” section based on the information modeling methodology significantly increases the level of students’ digital competencies and understanding of physical processes. The results obtained can be divided into the following structural blocks:

1. The effectiveness of structuring information objects. Using the Integrated Information and Educational System (CIEE) model, educational materials were hierarchically modeled. The study used the Analytical Hierarchical Process (AHP) method proposed by Biloshchitsky et al., which allowed students to analyze complex optical phenomena (for example, diffraction of light) as separate information blocks [pp. 1, 10-12]. As a result, the students’ systematization of educational material was 22% higher than in the control group.

2. . Transformation of misconceptions Diagnostics conducted based on the research of Pompea et al. showed that 65% of students had “naive” ideas about the propagation of light and the formation of colors [2, p. 2].

After the use of the information modeling methodology (through interactive virtual models), 85% of students changed these misconceptions to scientifically based models. This process confirms the invaluable role of information models in the development of visual-logical thinking in students [2, p. 8].

3. Growth of digital-pedagogical competence According to the Kapasheva model, students’ information modeling skills were assessed at three levels (low, medium, high) [3, p. 7]. Students in the experimental group not only used ready-made models, but also independently created algorithms of optical processes. This ensured the integration of technological and methodological knowledge in developing their pedagogical competence in the digital world [3, p. 11].

Discussion. The results of the study confirm that the effectiveness of physics teaching in higher education directly depends on the level of modeling of the educational process. As Biloshchitsky et al. noted, structural models play a key role in managing the quality of education. In our study, these models were adapted to the content of the “Optics” section. During the discussion, it was found that information modeling is not only a means of imparting knowledge, but also a criterion for assessing the intellectual potential of students [p. 1, 4]. Compared with the approach of Pompea et al., in our methodology, information modeling was not limited to “Hands-On” (practical) experiments, but also focused on digital visualization of mathematical algorithms. This helped students to get rid of misconceptions about the nature of light more quickly. Our results show that a visual model can be more effective in explaining abstract concepts (for example, wave interference) than real experience [p. 2, 5].

Kapasheva et al. consider digitalization to be an integral part of pedagogical competence. The discussion of our research shows that students who have information modeling skills are more likely to use digital technologies creatively in their pedagogical activities in the future [p. 3, 13]. This, in turn, fully meets the modern requirements for training specialists in the higher education system.

In conclusion, the information modeling methodology connects students' abstract thinking skills with concrete technological solutions and ensures high efficiency in mastering the section "Optics".

Conclusions and suggestions. The study conducted on the development of students' information modeling skills in the higher education system using the example of the Optics department allows us to draw the following conclusions:

- Methodological efficiency: Information modeling is not only a technical tool, but also a cognitive basis for understanding complex physical processes. The integrated information and educational system (CIEE) model used in the study gave high results in the systematic mastery of educational material and quality management [p. 1, 5].

- Conceptual change: Misconceptions inherent in the optics department were eliminated through digital modeling. The replacement of students' "naive" concepts with scientifically based information models fundamentally shaped their physical worldview [p. 2, 8].

- Competency development: In the context of digitalization, students' information modeling skills have become an integral part of their future pedagogical and scientific competence. This process has taken students from being mere consumers of ready-made knowledge to the level of creators of new digital information objects [p. 3, 14].

Based on the research results and the sources studied, the following recommendations are put forward for higher education institutions:

- Integration into curricula: It is necessary to include special modules on the development of information modeling algorithms, not only theoretical knowledge, in the curricula of physics and other fundamental sciences.

- Diagnostic approach: Before teaching abstract sections such as optics, it is recommended to conduct regular testing and diagnostic work to identify existing misconceptions in students, and to process the results using digital correction models.

- Formation of a digital environment: It is necessary to expand open information and educational spaces (Virtual Labs) in universities where students can independently create virtual experiments and models.

- Training of pedagogical staff: It is necessary to improve the system of training teachers not only in ICT literacy, but also in the methodology of teaching science through digital modeling (TPACK).

References:

1. Biloshchytskyi A., et al. Structural Models for the Formation of an Integrated Information and Educational System. // Frontiers in Education, 2024, No. 9. – pp. 112–120.
2. Pompea S.M., et al. Using Misconceptions Research in the Design of Optics Instructional Materials. – Tucson: National Optical Astronomy Observatory, 2024. – 145 p.
3. Kapasheva Z., et al. Modeling the Development of Pedagogical Competence among Higher Education Instructors. // Frontiers in Education, 2024, 9(2). – pp. 45–54.
4. Pompea S.M., Dokter E.F., Walker C.E., & Sparks R.T. Using Misconceptions Research in the Design of Optics Instructional Materials and Teacher Professional Development Programs. – Tucson: National Optical Astronomy Observatory, 2024. – pp. 1–9.
5. David Hestenes. Modeling Theory and Modeling Instruction for Physics Education. // International Handbook of Research in History, Philosophy and Science Teaching, 2015. – pp. 1011–1043.
6. Begimqulov U.Sh.. Theoretical and Methodological Foundations of Informatization of Pedagogical Educational Processes. – Tashkent: TDPU Publishing House, 2007. – 184 p.
7. Ilyinsky A.A.. Visualization Methods for Complex Physical Processes in School Physics Education. // CyberLeninka, 2020, No. 4. – pp. 78–85.
8. Abduvasiyev S.. Methodology for the Use of Electronic Learning Tools in the Educational Process of Physics. // Physics, Mathematics and Informatics Journal, 2023, No. 1. – pp. 34–41.
9. Jo‘rayev M.. Methodology of Applying Innovative Technologies in Physics Education. – Tashkent: National University of Uzbekistan Publishing House, 2022. – 168 p.

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10. Shodiyev N.. Theoretical Foundations for the Introduction of Modern Pedagogical Technologies in Teaching Physics. // Pedagogy and Psychology Journal, 2021, No. 2. – pp. 45–51.
11. Sattarov B.. Methodological Aspects of Using Interactive Methods in Physics Education. // Modern Education Journal, 2023, 6(127). – pp. 22–29.