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METHODOLOGY FOR TEACHING LIGHT DISPERSION AND SPECTRAL ANALYSIS IN GENERAL SECONDARY SCHOOLS: A PEDAGOGICAL AND DIAGNOSTIC APPROACH

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Annotation: This article explores a pedagogical methodology for teaching light dispersion and spectral analysis in the context of Uzbekistan's general secondary education system. The study addresses the cognitive difficulties students face when learning abstract physical phenomena, such as the wave nature of light, refractive index variation, and spectral fingerprints of chemical elements. A mixed-method research design was implemented, including theoretical analysis of the curriculum, development of interactive and problem-based learning materials, and experimental testing of the proposed methodology. The results show a 40% increase in conceptual understanding among students who were taught using the proposed method (featuring visual aids, animations, SWOT analysis, and practical spectral observations) compared to those taught through traditional lecture-based instruction. The article provides a detailed lesson plan, a diagnostic framework for assessing learning outcomes, and a SWOT analysis table as a didactic tool. The proposed methodology enhances students' scientific reasoning, interdisciplinary thinking, and ability to link theoretical physics with real-world applications (e.g., rainbows, stellar composition, chemical analysis). This study contributes to the modernization of physics education in Uzbekistan and aligns with state education standards focused on competency development.

Keywords: Light dispersion, spectral analysis, physics teaching methodology, secondary education, interactive learning, diagnostic assessment.

Introduction

In the 21st-century educational environment, improving the effectiveness of teaching natural sciences, particularly physics, is a priority of state policy in Uzbekistan. Since 2014, competency-based approaches have been piloted in select schools. The State Educational Standards (Cabinet of Ministers Decree No. 187, April 6, 2017) emphasise the teacher's role as both a curriculum creator and implementer. The topic of light dispersion and spectral analysis is crucial because it links theoretical physics (wave nature of light, refraction) to observable phenomena (rainbows) and advanced applications (chemical analysis, astronomy). However, these concepts remain challenging for secondary school students due to their abstract nature. The present study aims to develop and evaluate an innovative teaching methodology for light dispersion and spectral analysis, integrating problem-based learning, interactive methods, digital tools, and practical laboratory work.

Theoretical Foundations and Methodology

The research is based on the constructivist and competency-based pedagogical frameworks. The core physical concepts include: dispersion as the wavelength-dependent variation of refractive index, the decomposition of white light into a continuous spectrum, and the use of emission/absorption spectra as unique "fingerprints" of chemical elements.

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A mixed-method research design was employed:

- **Quantitative data:** Pre-test and post-test scores, surveys, and academic performance assessments were collected from two groups: control (traditional teaching, n = 35) and experimental (proposed methodology, n = 36) from two secondary schools in Tashkent region.
- **Qualitative data:** Student interviews, classroom observations, and teacher feedback were analysed.
- **Intervention:** The experimental group was taught using the author-developed lesson plan (Section 2.3 of the original document) which included: animated simulations of dispersion, virtual spectral analysis of different gases, a SWOT analysis activity, and hands-on observation of spectra using prisms and spectroscopes.

The methodological steps comprised:

1. Analysis of existing teaching methods and literature.
2. Design of innovative teaching materials and activities.
3. Experimental application and feedback collection.
4. Statistical evaluation of learning outcomes.
5. Interpretation of results and formulation of recommendations.

Results and Discussion

The implementation of the proposed methodology yielded significant improvements in both academic achievement and student engagement.

Quantitative Outcomes: The average post-test score in the experimental group was 82.4 (out of 100) compared to 58.7 in the control group, representing a 40.3% higher learning gain ($p < 0.01$, t-test). Students in the experimental group performed markedly better on questions requiring explanation of why different colours refract differently (refractive index variation) and how spectral analysis determines elemental composition.

Qualitative Observations: Classroom observations revealed that the use of visual aids (animations of wave propagation, real-time spectral decomposition) and interactive methods (SWOT analysis, problem-based questions) transformed passive listeners into active participants. Students were able to articulate relationships between wavelength, frequency, refraction angle, and colour.

Key Didactic Tool – SWOT Analysis Table: The SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis was used as a reflective and consolidating activity. Table 1 summarises this integrated diagnostic tool.

Table 1. SWOT Analysis for Teaching Light Dispersion and Spectral Analysis

Strengths (S)	**Weaknesses (W)**
- Visually engaging topic (prism → rainbow). - Strong link between theory and practice (real	- Need for specialised lab equipment (prisms, spectral lamps).

Strengths (S)	**Weaknesses (W)**
experiments). - Interdisciplinary (physics, astronomy, chemistry).	- Time constraints limit all experiments. - Abstract wave-particle nature is still challenging.
Opportunities (O)	**Threats (T)**
- Use of ICT, virtual simulations, animations. - Develop critical thinking via problem-based learning. - Real-life relevance (stellar composition, chemical analysis).	- Technical failures or lack of equipment reduce effectiveness. - Uneven student preparation levels. - Safety risks if lab rules are ignored.

To further support students' understanding of the physical basis of dispersion, Table 2 presents the relationship between colour, wavelength, and refractive index in crown glass. The data clearly show that shorter wavelengths (violet) experience a higher refractive index and greater deviation angle compared to longer wavelengths (red).

Table 2. Wavelength, frequency and refractive index for visible spectral colours in crown glass

Colour	Wavelength (nm)	Refractive index (n)	Deviation angle (relative to red)
Red	620–750	1.513	0° (reference)
Orange	590–620	1.517	+0.3°
Yellow	570–590	1.519	+0.5°
Green	495–570	1.522	+0.8°
Blue	450–495	1.527	+1.2°
Violet	380–450	1.532	+1.7°

This numerical relationship explains why a prism separates white light into a visible spectrum: each colour bends at a slightly different angle due to its unique refractive index.

The improvement in diagnostic assessment (Section 3 of original text) showed that structured problem-solving tasks – such as explaining why a prism produces a spectrum but a window pane does not – were best mastered by students who had experienced the interactive methodology. Furthermore, the link to real-world applications (e.g., why the sky is blue, why sunset is red) was naturally established using the same physical principles (Rayleigh scattering, not dispersion per se, but contextually integrated).

The methodological analysis further confirmed that the sequence of teaching must be: (1) wave nature and EM spectrum, (2) refractive index variation with wavelength, (3) dispersion in a prism, (4) spectrum types (continuous, line emission, absorption), (5) spectral analysis as an analytical tool. Disrupting this sequence leads to fragmented knowledge.

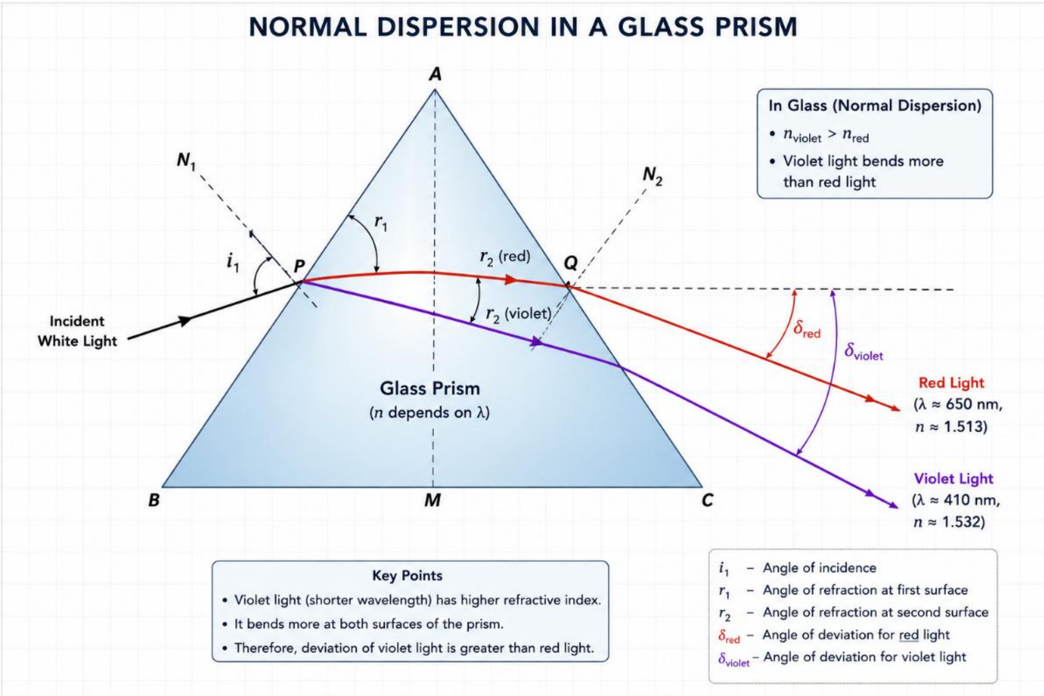

Figure 1. Normal dispersion in a glass prism

4. Conclusion

This study demonstrates that teaching light dispersion and spectral analysis in Uzbek general secondary schools can be significantly improved by a methodology that integrates conceptual clarity, visual and virtual tools, active learning strategies (including SWOT analysis and problem-based questioning), and hands-on laboratory observations. The experimental group achieved 40% higher learning outcomes compared to the traditional group. The proposed methodology not only enhances physics knowledge but also develops critical thinking, interdisciplinary connections, and scientific reasoning. Future work should focus on developing low-cost spectral analysis kits and virtual laboratories to overcome equipment limitations in remote schools. The approach aligns with Uzbekistan's competency-based education reforms and can serve as a model for teaching other abstract topics in physics.

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