Research-Based Proposals on Optical Spectroscopy and Secondary Students' Learning Outcomes

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Abstract. In the theoretical framework of the Model of Educational Reconstruction, with Design-Based Research methods, we designed an educational path on optical spectroscopy for secondary school students. We implemented the activities in different contexts. By means of tutorials, pre- and post-tests informed by existing physics education research literature, students' learning outcomes are systematically monitored. The educational path and the learning outcomes of the implementations are presented together with the used materials.

1 Introduction and aims

Optical spectroscopy is a significant referent that provides the experimental basis of atomic structure and light-matter interaction, as well as the conceptual bridge from classical to modern physics. Despite its relevance from the disciplinary viewpoint, very few efforts have been made to integrate it coherently in secondary school curricula.

Previous Physics Education Research (PER) studies about students' conceptions about optical spectroscopy evidenced that the main difficulties regard: (i) the association between spectral lines and energy levels [1]; (ii) the idea that every transition always takes place at the ground level [1,2]; (iii) the wrong interpretation according to which the emitted radiation is linked only to the final or initial level involved in a transition [2]; the idea that the number of distinct colors in a spectrum is equivalent to the number of energy levels [1]. The role of the ground level is often controversial: some research studies pointed out that it is not considered as an energy level [1], or corresponds to zero energy [1,2]. Such conceptions plausibly underlie the difficulty in assigning a meaning to negative energy values of the excited levels [1]. The Bohr model of the hydrogen atom is incorrectly used to link the orbits with the energy levels, thus misinterpreting: (i) the symbolic representation of the orbit; (ii) the relationships between spectral lines and the microscopic structure; (iii) the role of the photon in the $E = h \cdot f$ relationships [3]. Conceptual difficulties related to the energy quantization of the radiation concern the idea that a photon can be partially absorbed, or the idea according to which the atom must always make a transition between levels, although the energy of the photon does not allow it [2]. The idea that the radiation intensity is linked to the energy of the photons rather than their number has also been detected [2,4]. Difficulties concerning the role of the experimental setup in spectroscopy labs has finally been pointed out [1]. In particular it emerges the idea that the spectra of a source depend on the experimental setup used to detect it.

Based on above results in PER literature, we designed by means of Design-Based Research (DBR) methods [5] in the theoretical framework of the Model of Educational Reconstruction (MER) [6] an educational path on optical spectroscopy, designing and testing single intervention modules.

2 Methods

2.1 Design of the proposed path on Optical Spectroscopy

The educational path was designed to actively involve secondary school students in experimental and interpretative tasks providing the foundational basis for optical spectroscopy. The activities allowed to highlight the link between the energy-levels model of atoms and light emission observed with simple and low-cost spectroscopes. Our educational approach involved the reconstruction of the disciplinary contents from an educational point of view: we analyzed the main conceptual knots and interpretative problems as emerged from the history of physics and correspondingly designed conceptual micro-steps in which active learning strategies were used to overcome known misconceptions and to foster the appropriation of the foundational disciplinary key ideas. Interpretative issues related to the analysis of simple optical spectra from different sources were problematized using Inquiry-Based Learning strategies.

2.2 Implementation of the proposed path on Optical Spectroscopy

Six different interventions were carried out including the assessment of learning outcomes by means of pre-tests, post-tests and tutorials with 172 17-18 years-old students from 11 different classes. The same core and rationale of the path characterized the different interventions, however, the specific didactical trajectories differed in the order of the stimuli problems submitted to the students. The problem of characterizing a light source, and the properties of the emitted light and the existence of colored lights provided a fruitful context for a review of different light sources, including the description also the physical principles at the basis of their functioning. The issues in the production and nature of colored light and the emission mechanisms are subsequently addressed. The use of easy-to-build spectroscopes enriched the activity, allowing students to observe different kind of spectra. A problem-solving activity was proposed to reproduce the historical reconstruction of the Balmer's empirical formula for the first four lines in the visible hydrogen spectrum, and to introduce Rydberg's interpretation in terms of differences of homogeneous quantities accounting for the position of different emission lines, thus interpreting them as the energy levels. A wide spectrum of exercises, ranging from energies, levels and discrete emission in a spectrum and vice-versa allowed to elicit the main conceptual difficulties and to set up suitable strategies to overcome them and to gain mastery in describing microscopic world from optical spectroscopic data. Results from qualitative analysis will be presented and discussed.

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