An educational proposal on optical spectroscopy for secondary school students

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- Conceptual knots on OS
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Optical spectroscopy & PER

Interpretative problem concerning the link between classical physics (CP) and modern physics (MP) in the history of physics is twofold:

- Interpretation of the atomic structure of matter
- Nature of radiation

**OPTICAL SPECTROSCOPY** is the link to set up a coherent framework able to describe involved processes, representing a bridge between CP and MP.
Optical spectroscopy & PER

The study of discrete optical spectra offers an important disciplinary contribution on the epistemological plan of physics, since absorption and emission of quantized radiation are fundamental concepts, representing some of the main investigative tools based on light-matter interaction.

PER studies about secondary and university students’ conceptions about OS evidenced several learning difficulties, in particular concerning spontaneous models on the formation of discrete spectra and of their links with the quantized structure of atoms.

A Design-Based Research (DBR) approach helped in designing, in a three-years-long process, different educational proposals for secondary school students on optical spectroscopy. The proposals have been put into practice in different contexts, and the various stages of the whole experimentation will be here presented, discussing the main learning outcomes.
Problems and challenges faced during history of physics are often implicitly found in educational settings in textbooks and in scholastic practice in different disciplines (physics, chemistry, biology, astronomy). Examples are:

- Interference and diffraction phenomena addressed only following a wave approach
- Description of structure of matter using uniquely a Bohr-Sommerfeld model (orienting to a spatial representation of the atom)
- The concept of orbital
- Reading and interpretation of spectra
- Last, but not least, the role of the components of a spectroscope
Research on T/L
A quick glimpse to literature

- The energy of a spectral line is the energy of a single energy level (Zollman et al, 2002; Rebello et al, 1998);
- The energy of the radiation is linked to the intensity rather than the color (Lee, 2002);
- The ground level is not a level, the ground level is involved in every transitions, the spectra of a source depends on the experimental setup used to detect it (Ivanjek, 2012; Ivanjek et al, 2015; Korhasan & Wang, 2016);
- Students do not have a correct model of the quantization of energy on atoms and in radiation, so they struggle in predicting the way they interact (Savall-Alemany et al, 2016).
Research on T/L
A quick glimpse to literature

- Students in introductory astronomy courses struggle to understand the nature and causes of emission and absorption line spectra (Bardar et al, 2006);
- Students struggle to derive information about elemental composition, temperature and motion in emission and absorption spectra (Lee & Schneider, 2015).
Research on T/L
A quick glimpse to literature

- Researches evidence the presence of students’ spontaneous models concerning discrete spectra formation and their relationship with the quantized structure of the atom.
- Such models have to be overcome in order to reach a scientific view of the topic (Gilbert et al, 1998).

“Three lines are formed from possible combinations from $E_n$ to $E_o$.”

Korhasan & Wang, 2016

Ivanjek et al, 2015
Basis of the research

- Build an educational path on spectroscopy in the theoretical framework of the **Model of Educational Reconstruction** (MER) (*Duit et al., 2005; Duit et al., 2012*);
- Design and test micro-steps of the path in a **Design-Based Research** (DBR) environment (*Anderson & Shattuck, 2012; DBR Collective, 2003; Collins et al., 2004; Van der Akker et al., 2006*);
- **Inquiry-Based-Learning** (IBL) methods: students are asked to describe and interpret phenomena during experimental activities (*McDermott et al., 2000*);
- **ISLE** methods + LAB (*Etkina & Van Heuvelen, 2001; Etkina et al., 2002*);
- Analyze learning processes using **Qualitative Methods** (*Mayring, 2004; Otero & Harlow, 2009*).
Basis of the research: the MER

The Model of Educational Reconstruction (MER)
(Duit et al, 2005; Duit et al, 2012)

The educational approach to optical spectroscopy needs a reconstruction of the contents from an educational point of view starting from the founding cores of the topic, an analysis of the main conceptual knots and the main interpretative problems that have emerged from the history of physics, an exploration of students' spontaneous ideas.
Basis of the research: DBR approach

The design and test of educational proposals, composed by conceptual micro-steps, have to be revised according to the outcomes of the various trials.

**Design-Based Research (DBR)**
(Anderson & Shattuck, 2012; DBR Collective, 2003; Collins et al, 2004; Van der Akker et al, 2006)
Basis of the research: our choices

We pointed out some aspects of the rationale representing conceptual knots concerning the interpretation of spectra.

- Approach starting from optics, in particular from light sources;
- Energy as the main conceptual referent for decoding a spectrum;
- Comparison between continuous, discrete and band spectra, searching for an interpretation;
- Experimental exploration;
- “Artifacts method”: role of each part of a spectroscope;
- Linking macro-micro;
- History of science supporting concepts, rather than a pure historical approach.
The rationale of the proposal

<table>
<thead>
<tr>
<th>Phase</th>
<th>Protocol step</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ph1</td>
<td>The three perspective in optics</td>
</tr>
<tr>
<td>Ph2</td>
<td>The mechanism of vision</td>
</tr>
<tr>
<td>Ph3</td>
<td>The nature of colors</td>
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<tr>
<td>Ph4</td>
<td>Light sources</td>
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<tr>
<td>Ph5</td>
<td>Light emitted by different sources</td>
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<td>Ph6</td>
<td>Exploration with spectroscope</td>
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<td>Ph7</td>
<td>The spectroscope</td>
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<tr>
<td>Ph8</td>
<td>Phenomenology of diffraction</td>
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<tr>
<td>Ph8.1</td>
<td>Phenomenology of diffraction (IBL approach)</td>
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<td>Ph9</td>
<td>Energetic interpretation of colors</td>
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<tr>
<td>Ph10</td>
<td>Balmer and Rydberg’s formulae</td>
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<tr>
<td>Ph10.1</td>
<td>Rydberg’s formula (wavenumber)</td>
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<tr>
<td>Ph10.2</td>
<td>Rydberg’s formula (energy)</td>
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<td>Ph11</td>
<td>Bohr’s model</td>
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<td>Ph12</td>
<td>Link between lines and energetic levels</td>
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<tr>
<td>Ph12.1</td>
<td>From levels to lines</td>
</tr>
<tr>
<td>Ph12.2</td>
<td>From lines to levels</td>
</tr>
</tbody>
</table>
The rationale of the proposal
Key issues – observing different light sources with a spectroscope

Sun

Incandescent bulb

Alogen bulb

Smartphone monitor (yellow)

Fluorescent lamp

Na Street light

White LED

Hydrogen

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The rationale of the proposal
Key issues – the historical approach searching for an interpretation

Students are directly involved, with their own reasoning, in reconstructing Rydberg’s formula starting from Balmer’s coefficients.

READING OF EMPIRICAL RESULTS

RE-ARRANGEMENT FOR A GENERAL LAW

GOAL: Overcome the classical orbit model in favor of an energy-levels model.

\[ \lambda_n = k \left( \frac{n}{n^2 - 4} \right) \]

9/5
4/3 (=16/12)
25/21
9/8 (=36/32)

\[ \frac{1}{\lambda} = k' \left( \frac{1}{4} - \frac{1}{n^2} \right) \]

INTERPRETATION OF THE LAW (LINKING MACRO/MICRO)

\[ E = h\nu = \frac{hc}{\lambda} \]
The rationale of the proposal

Key issues – lab activities
The cycles of experimentations

By means of DBR, in the framework of MER, we conducted 15 R-B intervention modules for class groups of 20-40 secondary school students (563 students in total: 229 18-19 y.o., 334 17-18 y.o.) in order to design T/L sequences able to overcome the main conceptual knots.

<table>
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<tr>
<th>INTERVENTION ID</th>
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<th>NUM. CLASSES</th>
<th>MONITORING INSTRUMENTS/SAMPLE NUM.</th>
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<td>S_18_TUTORIAL 20 -</td>
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</table>

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The cycles of experimentations

3 approaches

**LS:** The path starts with analyzing light sources and the emitted light from a technological, functional and social point of view searching for physical interpretation of the mechanism emitting light.

**PH:** Students use a spectroscope, without knowing its functioning, to analyze spectra from different sources, the mechanism of diffraction is analyzed in sequel of the path.

**CD:** A more traditional sequence of reasoning is implemented, starting from geometrical optics, through the interpretation of color as a physical quantity; the path is thus embedded in a traditional optics course, deepening some crucial aspects as the light matter-interactions.

2 perspectives

**E:** The interpretation of light as a wave is completely neglected in favor of an energetic interpretation of the emission of radiation that also justifies the spectra.

**W:** The empirical Balmer coefficients are interpreted, which describe the succession of wavelengths, to then obtain a formula of general validity, expressed in wave number (Rydberg) and with Einstein's hypothesis of the photoelectric effect, it allows to interpret the lines as energetic jumps.
Some conclusive remarks

Qualitative analysis of students’ written answers allowed to assign significance to data collected in order to obtain indications concerning the usefulness of the proposed activities in the various stages of the research and the subsequent re-designing of the questionnaires and the refinement of the educational path.

As an example, analysis of optical diffraction has been gradually implemented in the proposals due to students' emerged difficulties in distinguish an optical spectra from a diffraction pattern, or the description of the energy state of an atom using its energy levels, rather than an atomic model making use of orbits, turned out to be more effective in gaining a conceptual understanding of the phenomenology.

Thanks to a DBR approach, it is possible to point out the best strategies to design the setting up of effective educational interventions, in particular, a methodological approach in which qualitative and quantitative explorations of phenomena are performed seems to be fertile as well as specific activities in which students are asked to interpret the involved processes, which is the founding core of optical spectroscopy.

Thanks to DBR: «content-related» strategies for educational interventions can be identified
Some conclusive remarks

Optical spectroscopy is a fertile field:
- In the context of new guidelines for Modern Physics curricula in SS
- As a link between optics and atomic physics
- As cross-topic thanks to the various stimulating applications (chemistry, astrophysics, art, ...)
- As a context in which energy is used to describe light-matter interactions
- Methodological and epistemic basis in physics: energy-based indirect measures in order to validate micro/macro models
- As a context to overcome several conceptual knots, as:
  - Role of devices in measuring (slit, grating, prism)
  - Difference between a diffraction pattern (spatial distribution) and spectra (energy distribution)
  - Conceptual difference between orbits and levels
  - Language: term “energetic level” misused by students (“energy state” to be preferred)

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