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Upper secondary school students conceptual learning of optical spectroscopy

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Summary. — A Teaching Intervention Module (TIM) on optical spectroscopy was designed in the theoretical framework of the Model of Educational Reconstruction. This study illustrates a proposal for a conceptual survey related to the TIM implemented in three classes of $N = 60$ high school students (18–19 years old). We focused the survey on the nature of colors and the interpretation of spectra. The data analysis was carried out through answers' categorization. The results show that the students acquired a good knowledge about the mechanism of spectra formation, but some aspects related to atomic emission (*e.g.*, ionization process) would need more clarification.

1. – Introduction and aims

In this study, we consider spectroscopic phenomena as playing a crucial role in adopting an interpretative model of the nature of light. For this reason, it is important to elaborate educational proposals aimed at overcoming learning difficulties related to this set of phenomena. In particular, literature clearly show students' difficulties in understanding the dispersion of light through a prism (*e.g.*, they often believe that light has no color, and a prism adds color to light) [1] and the nature of light in terms of coloring an object, as they think that colors are properties of the objects [2]. Furthermore, previous findings reports students' difficulties in associating the type of light source with the spectra characteristics: they use to identify discrete spectra as a kind of diffraction pattern [3] and to associate the spectral lines with the energy levels of atoms in a light source [4].

2. – The Teaching Intervention Module

The TIM we implemented was part of an educational path already experimented by our research group [5], developed according to the framework of the Model of Educational Reconstruction [6]. The main steps of the path are the following ones:

1) The color of objects and the color of light: the mechanism of selective absorption constitute a first interpretation of the objects' color. Therefore, the exploration of how different colored lights can be obtained, directly from the sources or by decomposition, leads to the discussion on additive and subtractive synthesis.

2) The energetic interpretation of colors: the analysis of the photoelectric effect leads to the hypothesis of the quantum nature of light, where color measures the energy of photons. Thus, the energy and intensity of light are made explicit as different quantities. In this way, different types of light sources are characterized by these quantities. The description of the color of light according to the quantity "energy" represents the conceptual referent of the proposal.

3) The spectroscope and the different types of spectrum: we discussed the role of the different parts of a spectroscope (tube, slit and grating). The spectra of the different sources were examined by phenomenologically identifying the types of discrete, continuous and band spectra.

4) The identification of a law for the spectrum of the hydrogen atom: the measurement of color was made using a photon model of light. On this basis, students receive the spectrum of the hydrogen atom and are invited to find a law that describes it. We were inspired by Balmer's reasoning, in which the prerequisites are only the 4 arithmetic operations. Thus, students are able to identify the law of the phenomenon following the proposal by Rydberg. They can recognize that the description of a spectrum is linked to the difference of two squared quantities. These are interpreted as the difference between energy states, aligning with Einstein's photon hypothesis.

5) The interpretation of emission spectra: the emission process is illustrated through the link between energy levels and spectral lines. The transition from energy levels to spectral lines is a different methodological and conceptual challenge than the reconstruction of the energy structure of an emitting system starting from its spectrum: both aspects were considered in the process.

The TIM was implemented in two lessons, 2 hours for each. The specific research questions that guided the study are:

(RQ1) How do students interpret the nature of colors?

(RQ2) How do students interpret the roles of the instruments providing spectra?

(RQ3) How do students interpret the emission spectra?

3. – Methods

A sample consisting of 60 Italian students was involved in this study. They were attending the last year of a scientific lyceum in Treviso. The schoolteachers did not provide any information about the addressed topics before TIM implementation. A conceptual survey was designed to investigate the addressed topics through open-ended questions. Several questions for the same topic are submitted, in order to investigate the level of coherence in students' reasoning. The data were collected online some weeks after the TIM implementation, under the supervision of the schoolteachers. To answer the research questions, the data were categorized for each item.

4. – Results

The results about the first research question are reported in table I, according to three main multiple-choice items. They also asked for an explanation of the answer provided, in order to find out any inconsistent reasoning. The large majority of students (53 out

Table I. – *Answers' categories for some items. For questions 2.A) and 2.B) the categories are not mutually exclusive. Blank answer are not included.*

1.A) *How can we illuminate a white sheet to see it violet?*	N
Additive synthesis	2
Prism refraction	5
Both methods	53
1.B) *What colors are the lines you would find looking with a spectroscope at the violet coming from a prism?*	N
Only violet	15
Only red and blue	15
Blue, red and violet	30
2.A) *Consider a continuous spectrum. Removing the prism, how will the spectrum change?*	N
It will not change	12
It will be not continuous anymore	9
The linear dimension will change	7
A white region will appear	35
2.B) *Consider a continuous spectrum. How will it change replacing the prism with a diffraction grating?*	N
It will not change	14
It will be not continuous anymore	14
The linear dimension will change	6
A white region will appear	6
Image in the mirror	3
Rainbow bands	5
3.A) *What will happen providing 10 eV to the hydrogen atom in its ground state?*	N
Transition to the first excited state	16
Transition to an intermediate state	27
It remains in the ground state	12
3.A) *What will happen providing 14 eV to the hydrogen atom in its ground state?*	N
Transition to the last bound state	17
Not enough information to answer	27
Ionization process	13

of 60) recognized that a specific color can be obtained both from addition synthesis and diffraction phenomena. This result is consistent with conceiving color —these questions are related to violet— as a specific and measurable physical quantity (51 out of 60 students), but just 15 of 60 participants were able to apply this information in the specific context proposed by the question 1.B). Indeed, half of the students state they would find not only violet, but also red and blue lines looking with a spectroscope at the violet color coming from white light passing through a prism.

The two main questions related to spectra formation are reported in table I with the resulting categories. They both refers to a continuous spectrum. Similar percentages of students stated that removing the prism (48 out of 60) or replacing it with a diffraction grating (46 out of 60), the continuous spectrum would change. These questions are reformulated from another instrument [4], in order to capture possible associations between the categories of the two items. We found that the majority of students (35 out 60 students) recognized that removing the prism we would obtain a continuous white light region, consistently with the fact that just 6 students gave the same answer when the prism is replaced a diffraction grating. Their explanations suggest that they attribute the same role to these objects in determining the shape of the spectrum, mostly without specifying it. Furthermore, the two items share other two categories, given by the predictions that the spectrum would not be continuous anymore, and that the linear dimensions would change. As we found other specific categories in question 2.B), prior results about confusing spectra observation with diffraction pattern are confirmed [4].

There are six main questions related to spectra interpretation. In this group of items, distractors are selected from the main common-sense ideas we found in literature [3, 5]. The results show that students found easier starting from energy levels (51 out of 60 participants gave the correct answer) than starting from differences between levels (39 correct answers). Most of the students were able to individuate the correct number of energy levels necessary to get a specific emission spectrum. Among who report a complete and correct justification, they adopt two different strategies: the former consists in trying attempts with different number of levels, the latter consists in applying combinatorics.

5. – Conclusions

Our results show that the TIM produced a significant level of conceptual learning. The effectiveness of this TIM is also demonstrated by the data reported in literature on students' poor conceptual understanding of spectroscopy [5]. These results are not surprising, as in Italy and in many other countries these phenomena are not included in the modern physics curricula. Thus, it's worth continuing to investigate how to improve secondary school students' conceptual learning in this area. In this context, our next step of research will be investigate the models of light used by students to justify the spectra observation.

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