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

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Abstract. Optical spectroscopy is a conceptual referent linking classical and modern physics which provides experiments on the atomic structure and light-matter interaction. Its disciplinary relevance, as well as its importance on the cultural and social levels is widely recognized but few efforts have been made to integrate those aspects in education. Our Physics Education Research Unit from Udine University (Italy) designed an educational method on optical spectroscopy for secondary school students to directly involve them in experimental and interpretative tasks which allow them to highlight the link between energy level in atoms and luminous emission. In the theoretical framework of the Model of Educational Reconstruction, the educational approach involves an analysis of the main conceptual knots on the basis of a significant - if not vast - literature concerning the interpretation of optical spectra. By means of design-based research methods, we designed several intervention modules in which interpretative issues related to the analysis of simple optical spectra from different sources are highlighted using inquiry-based learning strategies. Learning outcomes were monitored by means of empirical research using pre/post-tests and tutorials.

1. Introduction and research perspective

Nowadays modern physics is recognized as indispensable in all European secondary school curricula, but there are still problems concerning which strategies to be employed [1]. Optical spectroscopy is a context that provides an experimental basis for the atomic structure of matter and modern quantum theory. Moreover it provides a significant methodological example of how physics makes use of indirect measures of energy in order to obtain information and validate models. Focused experimental activities that can be carried out with simple and cheap spectrometers allow us to highlight the link between atomic energy levels and corresponding luminous emissions.

The Physics Education Research Unit of Udine University is designing an educational path on optical spectroscopy for secondary school students, which directly involves them in experimental studies and interpretations related to microscopic phenomena involving light-matter interaction. From a research perspective, the design of an educational path starts with the analysis of the known conceptual knots, and a study of Physics Education Research (PER) literature on optical spectroscopy, despite it not being very wide, has shown that the main learning difficulties concern the conceptual link between discrete emissions and energy levels in atoms and the experimental conditions under which a discrete spectrum rather than a continuous one can be observed. Secondary school and university students tend to associate the energy of a single emission line with the energy of a single energy level, rather than to the difference between couples of levels [2, 3]. In introductory astronomy courses, where spectroscopy plays a key role, difficulties emerge in describing the process of luminous emission from atoms [4]. The problem of the conceptual link between spectral emissions and energy levels has also emerged in studies conducted by university students [5, 6, 7].



The same research shows that students are not aware of the experimental conditions necessary to produce a spectrum. Other researches [8] have also shown that secondary and tertiary level students, as well as secondary school teachers do not have a clear idea of the quantum model for atoms, nor of the quantum model for light, so they struggle to predict the way these models interact in emission and absorption processes. Evidence has emerged to prove the existence of spontaneous models concerning the formation of discrete spectra and of their links with the quantized structure of atoms. Those models have to be overcome in order to reach a scientific view of the topic [9]. In the theoretical framework of the Model of Educational Reconstruction (MER) [10, 11] by means of Design-Based Research (DBR) methods [12, 13, 14, 15] the educational approach to optical spectroscopy necessitates a reconstruction of the contents from an educational point of view, an analysis of the main conceptual knots and the main interpretative problems that have emerged from the history of physics and the design of conceptual micro-steps, in which active learning strategies make it possible to overcome any conceptual knots.

An educational proposal for secondary school students on optical spectroscopy will be presented with the aim of overcoming the conceptual knots evidenced in literature with an organic path integrating experimental activities. The proposal has been put into practice in different contexts: masterclasses, CLOE (Conceptual Lab of Operative Exploration) and a summer school for gifted students. All experiments occurred within the parameters established by the IDIFO6 project of the national project PLS (Progetto Lauree Scientifiche - Scientific Degree Project)¹.

Learning outcomes and difficulties that resulted from the experiments will be discussed, in particular: i) which microscopic models spontaneously emerged; ii) the spontaneous ideas regarding the conceptual link between spectral lines and energy levels; iii) the operational difficulties.

2. The educational path

An educational approach concentrated on the common sense ideas of students as a necessary condition in order to activate the learning process [16]. The educational path thus includes exploration activities and identification of the representations used by students to correlate macroscopic observations (spectral emissions) and the microscopic world (energetic structure of matter), in particular the spontaneous ideas concerning the interpretative aspects of the microscopic structure of matter causing luminous emissions. The following conceptual structure describes the core of the experimented educational path, highlighting its different steps (S).

S1 - The different perspectives in the field of optics. An analysis of the three big areas in which the study of optics can be framed (light sources, propagation of light and interaction with matter) and of the three different perspectives (emission processes, description and formalization of optical ray-tracing and the different ways in which light can interact with matter) allow to build the basic idea of light as an entity travelling in space with no mass, but that can be described as a specific energy that contributes to the description of light-matter interactions producing different effects (heating, penetration, ionization and fluorescence). The aim is to discuss the difference between Snell's law and the transmission of the light through a transparent medium in order to distinguish the phenomenological description plan (represented by the laws of refraction) and the interpretative plan in terms of energy in which the microscopic interactions are analyzed.

S2 - The mechanism of vision. The problem of what does mean "to see" is proposed in order to identify, from an analysis of students' spontaneous models, the role of the observer, of the light and of the observed object.

S3 - The nature of the colors. The radiation assumes a significant role in the mechanism of the vision, posing the problem of what does the propriety "color" mean, starting from examination of painting illuminated with different lights. Mechanisms of selective absorption and nano-structuring explain the mechanism thanks to which the perception of the color of an object depends on the light used to illuminate it.

S4 - Light sources. A review of different natural and artificial light sources helps in recognizing a light source as a system able to transform energy and in recognizing the problem of interpreting the

¹ <http://www.fisica.uniud.it/URDF/laurea/idifo6.htm>

emission processes. This represents a valid context to reinforce the idea that the generation of light is a process that has to be read in energetic terms. The different light sources as incandescent, fluorescent lamps, LEDs and gas-discharge lamps (figure 1) are examined from a structural point of view, according to the emission processes and the emitted light, discussing the technological characteristics.



Figure 1. Different kinds of lamps are used in the path: incandescent, halogen, fluorescent, white and colored LEDs, gas discharge.

S5 - Light emitted by different sources. The characteristics of the light emitted by the sources are discussed: intensity and color. Concerning the color, the exploration of how different colored lights can be obtained leads to revisiting the additive and subtractive mechanisms of production of different colors, exploring if there are intrinsically colored light sources, also performing flame tests of different salts/elements. The presence of an energy exchange within a light source emerges from the analysis of the emission of an incandescent bulb: as the electrical power supplied to the system increases, light is obtained with different intensities and colors. The phenomenological laws of Stefan-Boltzmann, the identification of the emissive and absorbing power and the important law of nature that their relationship is only a function of temperature, directs the examination of the emission process with the increase of the power supplied to a source. The discovery of infrared radiation is set in this context in which the idea that the emission of radiation occurs at any temperature and that the radiation emitted by the bodies can be outside the visible are established. The historical discovery of ultraviolet radiation confirms this idea experimentally and allows to see the colors of the visible spectrum as different radiations. The problem of describing a white light is addressed recognizing Newton's double prism experiment showing how white light is composed of different colors.

F6 - Exploration with a simple spectroscope. The use of simple grating spectroscopes (figure 2) allows to characterize a light source based on the spectrum of the light emitted. The emission spectra of the various sources listed above are examined: the phenomenological exploration of the spectra allows to classify them into three categories: continuous, discrete and band spectra.

F7 - The structure of a spectroscope. The spectroscope is examined as an object itself, to recognize the functions, structure and role of the individual components (slit, reticulum, tube) with the artifact method [17] which leads to an initial global description, the subsequent discussion of the functions of the parts described and the constructive alternatives, in order to give meaning to the functional role of each component (figure 2).



Figure 2. A simple spectroscope: the grating and slit are evidenced.

F8 - The diffraction. Diffraction phenomena is experimentally studied with the acquisition of data of light intensity according to the position [18, 19] starting from the exploration of the distribution of the diffraction light intensity produced with single-slit monochromatic light, up to the examination of the light distribution produced by a diffraction grating, always in monochromatic light, thus giving diffraction the role of dispersive mechanism able to highlight the chromatic structure of light, previously highlighted by the interaction of light white with a prism (figure 3). Phenomenological laws can be derived from the same students (F8.1), addressing the issue with Inquiry-Based Learning (IBL) methodologies.

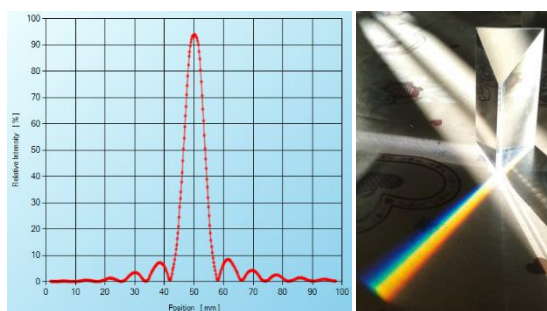


Figure 3. Different dispersive phenomena (diffraction, left and dispersion, right) are used to highlight the chromatic structure of light.

F9 - Energetic interpretation of the colors. The quantum nature of light in terms of photons whose energy corresponds to the color and intensity corresponding to the number of photons is based on the analysis of the photoelectric effect.

F10 - Balmer and Rydberg's formulae. An analysis of the hydrogen Balmer series (figure 4) is proposed as a context to look for regularities in the observed spectra. Students are thus directly involved with their reasoning to relive the historical development of ideas: the coefficients obtained by Balmer allow the reading of the experimental results in which the wavelengths of the first four lines of the visible spectrum of hydrogen are then obtained with the empirical formula $\lambda_n = k \cdot \left(\frac{n^2}{n^2-4}\right)$ [20], which is reprocessed by a law of general validity in terms of wave numbers (proportional to the energy in the light of the hypothesis of the photoelectric effect) $\frac{1}{\lambda_n} = k' \cdot \left(\frac{1}{4} - \frac{1}{n^2}\right)$, as obtained by Rydberg [20] to be associated with each color of the emitted radiation. The reading in energetic terms suggests that the energy of a specific light emission in a discrete spectrum is caused by a microscopic energy variation in the emitting system. In the first versions of the course the empirical formula was proposed to the students in terms of wave number (F10.1) or directly in energy (F10.2) searching for interpretations, in particular in the light of the hypothesis of the photoelectric effect. The history of physics in support of concepts plays an essential role here in reviving the same experience as Balmer

and Rydberg in identifying the rules with which the spectral lines can be described and then looking for an interpretation of the emission processes.

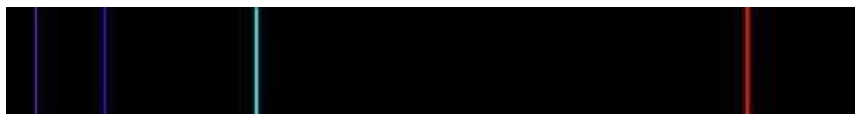


Figure 4. The first four lines in the optical spectra of hydrogen

F11 - Bohr's model. The original articles by Balmer and Rydberg inspire the operative proposal of analysis of the hydrogen spectrum and the drafting of the law of the first series of lines emitted by the hydrogen atom, whose structure inspires the hypothesis of description of the systems emitting for states of equilibrium and of emission as de-energization from energy levels. The semiclassical model of Bohr's atom allows to justify the negative value of the total energies that a bound system can take. The description in terms of energy levels is proposed with an analogy regarding the states of equilibrium assumed by a chair in a gravitational field. The energy state of the chair is described as the height at which the center of mass is placed when the chair system is disturbed: the center of mass of the chair leads to different levels of gravitational potential energy corresponding to the different configurations assumed. This is an effective and rigorous conceptual analogy developed by Golab-Meyer [21]. It is decided to describe the energetic state of an atom (which is not visible) in a similar way: a perturbation associated with an energetic transformation brings the atom into another state, which then decays losing the energy acquired in the interaction. The discovery of cadmium and rubidium highlight the important role of the spectrum in the recognition of the elements and clarify the periodic table of the elements available today in terms of the spectrum of each element.

F12. The link between discrete emissions and energetic levels. The emission process is explained by the link between the energy levels and spectral lines, whose nature in terms of energy of the lines, corresponding to energy differences between atomic levels requires consolidation exercises, in particular the drawing of energy levels and the relative emissions (F12.1) or vice versa the reconstruction of a structure of energy levels starting from a discrete spectrum (F12.2).

3. Context, sample and methodologies

The path has been experimented with 228 students aged between 17 and 18 from scientific lyceums. There were three contexts in which the experiments were conducted:

- Masterclass: involved students participating in an 8-hour long activity at university. Classes are led by the teacher who follows the activity and coordinates with the university, integrating content, strategies and methods during lectures at school.
- CLOE (Conceptual Laboratory of Operative Exploration): this activity has the same nature and setting of a masterclass, the only difference being that students are engaged in an activity that only lasts for 4 hours.
- Summer school on modern physics: a national selection allows a number of students to participate in a 6-day intensive activity at university which includes lectures, experiments and a focused educational path on different aspects of modern physics i.e. quantum mechanics, superconductivity, Franck-Hertz experiment etc... The spectroscopy part requires a total of 8 hours.

Masterclasses and CLOE activities involved different secondary schools from Veneto, one of the biggest regions of Italy. In the path, depending on the availability of time, two or three laboratorial activities were performed in groups: the optical goniometer experiment, the LED-ruler experiment and on-line diffraction measures from a single slit.

- The optical goniometer experiment. Involves the observation of discrete spectra at various orders produced by the interaction of the light emitted by a discharge lamp with a diffraction grating. The goniometer (figure 5) allows for the measurement of angles corresponding to various emissions. It is thus possible to evaluate the wavelength of a specific emission, using

the grating formula ($d \cdot \sin \theta = m \cdot \lambda$) and to convert this quantity in an associated energy ($E = \frac{h \cdot c}{\lambda}$)² according to Einstein's interpretations of the photoelectric effect.

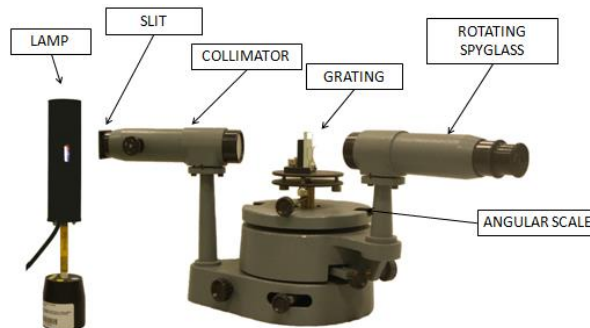


Figure 5. The optical goniometer experiment: emitted light from the lamp is collimated in order to make its direction of incidence perpendicular through the grating. Different chromatic components are thus angularly resolved and the rotating spyglass together with the angular scale allows to measure the corresponding angles.

- The LED-ruler experiment. It is assembled with low-cost materials and it allows one to observe the spectrum of the light emitted from a LED and to evaluate the energy corresponding to the dominant color: observing the LED through diffraction toy glasses makes it possible to observe its spectrum projected along a ruler and, with a simple trigonometric calculus, its diffraction angle and thus, the corresponding color energy can be calculated (figure 6). This quantity is put into relation with the triggering voltage of the LED. Thanks to these two experiments, students can observe and analyze different kind of spectra: a discrete as well as a continuous peaked one.

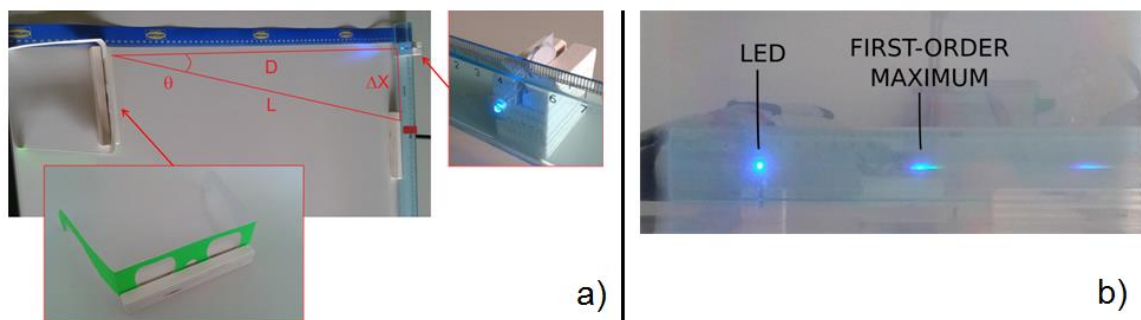


Figure 6. Low-cost experimental setup for observing the spectra of the light emitted from a LED and measuring the diffraction angle corresponding to the peak emission (a). observing through the grating the spectrum appears projected along the ruler (b).

- On-line diffraction measurements. A single slit diffraction phenomenon is explored with the aid of a patented sensor [18] allowing one to obtain a digitalized graph in which intensity is plotted against position along the screen. The analysis of the graph enables one to obtain the diffraction laws.

² In the relation $d \cdot \sin \theta = m \cdot \lambda$, d is grating's pitch, θ is the diffraction angle, with respect to the optical axis, of a particular wavelength λ in a particular order m . In the relation $E = \frac{h \cdot c}{\lambda}$, h is Planck's constant and c the speed of light.

The same conceptual core and rationale of the path characterized the different interventions; only the specific didactical trajectories revealed differences in the order of the stimuli problems submitted to students through Inquiry-Based Learning strategies [22, 23] Contents addressed in all experiment, as well as their sequence, were revised every time, as recommended by a DBR approach (table 1).

Table 1. Structures of the different educational paths as referred in the last column of table 2. Every column refers to a different experimentation, as defined in table 2. The numbers reflects the chronological order of the contents (Steps) addressed in every path.

Steps	Ma	Mb	Mc	CLa	CLb	Md	SEFM
F1 – The different perspectives in optics	1	1	1	1	1	1	1
F2 – The mechanism of vision	2	2	2	2	2	2	2
F3 – The nature of the colors	3	3	3	3	3	3	3
F4 – Light sources	4	4	4	4	5	5	4
F5 – Light emitted by different sources	5	5	5	5	4	4	5
F6 – Exploration with a simple spectroscope	7	7	7	7	6	6	6
F7 – The structure of a spectroscope	8	8	8	8	7	7	7
F8 – Diffraction	-	-	-	6	8	8	8
F8.1 – Diffraction (IBL approach)	6	6	6	-	-	-	-
F9 – Energetic interpretation of the colors	9	10	10	11	11	11	11
F10 – Balmer and Rydberg's formulae	-	-	-	-	-	-	10
F10.1 – Rydberg's formula (wavenumber)	-	11	11	-	-	-	-
F10.2 – Rydberg's formulae (energy)	-	-	-	10	10	10	-
F11 – Bohr's model	10	9	9	9	9	9	9
F12.1 – Levels drawing and emissions	-	12	12	12	12	12	12
F12.2 – From a spectrum to levels	-	-	-	-	-	13	13

Table 2. The path has been experimented in different settings, with different student samples and using different monitoring instruments ((a) pre-test, (b) post-test, (c) tutorial). In a DBR approach, the path underwent modifications in structure and in addressed contents, as highlighted in the last column (for details see table 1).

Date (2017)	Context	classes	Num studs	Instruments	Path
Jan, 26 th	Masterclass(a)	5I, 5L	43	(b), (c)	1
Feb, 1 st	Masterclass(b)	5B, 5M	33	(a), (b), (c)	2
Feb, 2 nd	Masterclass(c)	4D, 5D	47	(a), (b), (c)	2
Feb, 13 th	CLOE(a)	4A, 4C	22	(b), (c)	3
Feb, 14 th	CLOE(b)	4D, 4B	40	(b), (c)	4
Mar, 10 th	Masterclass(d)	5C	11	(b), (c)	5
Jun, 28 th	Summer School	4	32	(a), (b)	6

Masterclass	2h path	1h lab diffraction	3h path	2h lab spectroscopy
CLOE	2h path	2h lab spectroscopy		
Summer School	6h path	2h lab spectroscopy		

With regards to masterclasses and CLOE, different monitoring instruments were used: every student completed a guided tutorial (i.e. a worksheet with the same structure of the proposed path) with post-tests and, in some cases even pre-tests were conducted. The test-out was completed by students in their

classes and the outcomes were discussed with the all teachers involved as a collaboration between school and University. The post-test was structured in 13 questions (table 3). Concerning the summer school, the same test was used as a pre-test and a post-test and all were completed by students at the beginning and at the end of the activity.

Table 3. Requests in the post-test.

Questions	Requests
D1	Point out similarities and differences among various observed spectra and justify.
D2	Explain the emission process causing the observed emission lines
D3-D5	Describe the role of the grating and the slit
D6-D7	Describe the light emission process from an atom comparing the energies of the emitted radiation and those of the levels
D8	Draw a spectrum knowing the energetic structure of the levels
D9-D12	Draw the energy level structure given a discrete spectrum
D13	Sketch the energy structure of a LED and a gas discharge lamp given their emission spectra

4. Data analysis

The analysis of students' written answers was conducted with qualitative methods: written answers and drawings were classified in categories which were chosen a-priori, based on the research questions and the aspects that emerged from the students' answers. Each category is operationally defined according to students' expressions. The identified categories allowed data qualitative interpretations based on the emergent frequencies. In order to interpret ambiguous answers or drawings, it was sometimes mandatory to rely on clues present in answers or drawings of different questions.

Here we report some results that emerged from data analysis concerning answers 47 students gave to the most significant questions of the post-test of the experiment "Masterclass(c)" and the answers 32 students gave to a significant question in the pre- and post-test of the experiment that was conducted in the summer school for gifted students.

4.1. Masterclass(c) experimentation: post-test

With respect to the D1 question "Point out similarities and differences between light spectra from a incandescent lamp, a gas-discharge lamp and an LED, and justifying your answers" 38/47 answers were limited to describing spectra in terms of colors and/or present discontinuities, making analogies with the colors in a rainbow. 6/47 students interpreted a continuous spectrum as a consequence of thermal agitation (2/47) or to incandescence (2/47) and a discrete spectrum as a consequence of the nature of the emitting gas (1/47) or energetic jumps at atomic levels (1/47).

Question D2, referring to the experiment of the optical goniometer, asked to explain the process accounting for the observation of spectral lines, with the aid of a sketch. 23/47 students described the experiment in functional terms, eventually quoting diffraction as the mechanism responsible for the division of the colors. 8/47 students, on the other hand, interpreted the presence of different colored lines in terms of the microscopic process causing the emission in terms of transitions between orbits (5/47) or levels (3/47). 6/47 students use both a microscopic interpretation of light emission and a macroscopic description of the measurements apparatus. It emerged that the Bohr orbit model, which is used to describe jumps between orbits and/or indirectly used to account for the idea that an electron is localizable, is a conceptual referent for many students.

Questions D3-D5 test for the functional role of the slit and of the grating in accounting for the formation of a spectrum: 21/47 students believe that the shape of the slit is responsible for the shape of the lines, while, on the other hand, 11/47 students believe that it is the engraving on the grating that is responsible for it. Only a single student referred to the sharpness of the lines as a fundamental conceptual referent in a description of a discrete spectrum without taking into consideration that fact that lines can be differently shaped, according to the employed setup. A specific IBL explorative path

was particularly useful in this case since it offered students the opportunity to gain awareness of the functional role of every part of a spectroscope.

Issue related to the representation of the energy structure of the emitting system and the relative spectrum was addressed in question D8: the values of the first five energy levels of an ionized helium atom were shown to students who were then asked to represent them graphically and to sketch out the spectrum they expected to observe. 8/47 students employed “orbits” as conceptual referents, while 18/47 employed stacked “levels” as a more general representation, avoiding the use of the spatial representation of an atom (figure 7). Three models emerged that accounted for the formation of spectral lines with respect to the energetic structure of the emitting system (figure 8): a) a 1:1 correspondence between a line and a level (25/47), b) n close lines associated with n th level (4/47) and (c) all possible transitions (1/47).

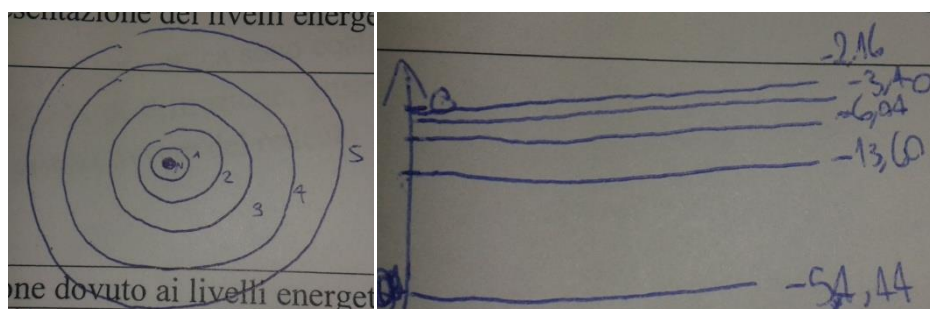


Figure 7. Models for atomic energy levels: orbits (left) and levels stacked with respect to an energy scale (right).

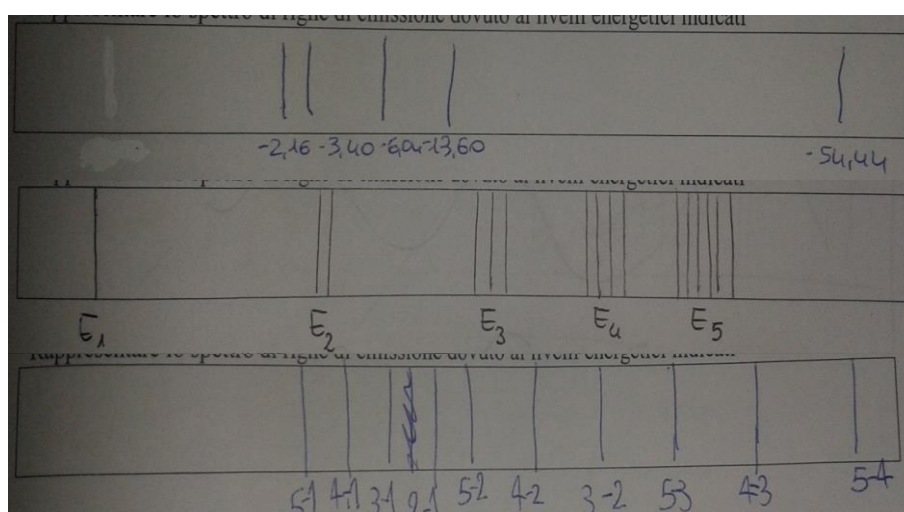


Figure 8. Given 5 levels, students expect 5 emissions in the spectrum (top), n close lines associated with n th level (centre) or all possible transitions (bottom).

4.2. Summer school experimentation: Pre- and post-tests

Answers to two significant questions of pre- and post-tests are analyzed and discussed below. The two questions were:

D1 “What do single energy levels represent in an atomic model?”

D2 “Considering that the first six energy levels of the hydrogen atom (values provided) how many emissions are expected? Justify your answer and draw the spectrum.” Answers to question D1 in the pre-test were given prevalently in terms of spatial localization of electrons in atoms, using orbits as conceptual referents (12/32), space where electrons can be found (4/32), orbitals (2/32) or distances from the nucleus (1/32), rather than in energy terms, using as conceptual referents electron energies (3/5), their exciting state (3/32) or the energy of the orbital (2/32). A minority of students indirectly

defined energy levels as the energy of emitted photons (1/32) or observed that the difference between the energy of two levels corresponds to the emitted energy (1/32). After the intervention³, students' answers, monitored with the post-test, showed a general trend against describing the electron in spatial terms, using conceptual referents as the space where electrons can be found (4/31), distance from the nucleus (3/31), orbits (2/31) or orbitals (2/31), in favour of descriptions in terms of properties of electrons in excitation state (9/31), energy (5/31), the property of not being able to emit radiation (4/31) or the energy of the orbital (1/31). A definition of energy levels is given in terms of characteristic energy of the system (6/31), in terms of an indirect definition relating the energy of the emitted energy to a difference between a couple of energy levels (5/31) or in terms of the energy of the emitted photons (1/32). It emerged that the perspective regarding the descriptions of energy levels in terms of spatial description using orbits rather than in terms of characteristics energies of the emitting system (i.e. the energy levels) was probably conditioned by what students had been taught previously at school.

Answers to question D2 allowed students to investigate the model they employed to foresee emissions in a discrete spectrum with only information regarding the energy values of the energy levels. Before the intervention, the spontaneous idea that a single level corresponds to a single emission line was quite prevalent (13/32). Out of those students, not one of them considered the fundamental level as an energy level. The interpretation according to which a single emission line is the outcome of a transition between a couple of levels was shared by 12/32 students (8 of whom considered all the transitions, 3 students considered only the ones involving the fundamental level and 1 student considered only transitions involving adjacent levels). Those interpretative models, based upon an arbitrary basis, were overcome by the end of the intervention, since it emerged from the post-test that all students adopted the model according to which all transitions were taken into account to justify the discrete emission in a spectrum.

5. Conclusions

A proposal for an educational path on optical spectroscopy for secondary school students, experimented in different contexts, has been presented and described together with some learning outcomes. The educational path has been designed in a DBR context in the theoretical framework of the MER. 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. Questions posed to students turned out to be fertile in the spontaneous production of models describing the energetic structure of matter accounting for discrete spectra, stimulating students in moving from a descriptive to an interpretative level, developing their functional reasoning. The proposed experimental activities enriched the activities, and the employed strategies can be implemented in a conceptual path, since starting from observations it is possible to find the interpretative basis of microscopic processes described by modern physics.

Optical spectroscopy is a fertile context in different areas: regarding the new guidelines concerning modern physics topics in scholastic curriculum, as a disciplinary deepening from optics to modern physics (i.e. in a vertical perspective linking different grades of instructions), as a transversal topic, thanks to the numerous application in chemistry, biology, astrophysics and art, which have a motivational and orienting role, as a context in which energy is used to describe light-matter interaction, and as a methodological and epistemic basis of physics, since indirect measures based on energy are used to validate models.

The aforementioned activities represent a fertile context for a collaboration between school and University, and the experimented path turned out to be a basis for the overcoming of some conceptual knots i.e. the role of a spectroscope in generating and detecting spectra, the difference between a diffraction pattern (which is an intensity distribution) and a spectrum (which is an energy distribution), difficulties related to linking spectral lines and energy levels, that can be caused by erroneous models of how spectral emissions are generated. The conceptual link between energy levels of a physical system (its states) and the orbits of the electrons, whose existence is out of discussion remains an

³ Only 31 students attended the post-test.

ongoing problem: the need for a clarifying step regarding the deep conceptual differences between the various representations and the various models emerged from the results. It is thus necessary, consider in the path not only the specific case of the hydrogen atom, in which the correspondence between orbits and levels is direct, and thus misleading, but also more general cases, as for example atoms with many electrons.

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.

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