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Seeing invisible colours: An on-line inquiry-based activity on electromagnetic radiation

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Summary. — We created a formal inquiry-based activity on electromagnetic radiation for high school students. The main topics of the activity are the electromagnetic spectrum and the matter response to different wavelengths, with a focus on visible, UV, near, and far-infrared. The activity is linked to some informal learning aspects from the scientific theatre of the Milan University project "The Show of Physics". The activity can be done remotely, by maintaining an inquiry approach. In this work, we present the didactic path and the first results obtained.

1. – Introduction

Electromagnetism learning and teaching involve some difficulties that have been described in the research literature in the past years [1-9]. In Italy, electromagnetism is an important part of the curricula for high school students and it is even fundamental for undergraduate ones. However, some topics, such as physics of colours, radiations' properties, detectors' functioning, are only mentioned briefly. Many students will not have the opportunity to study them after school. Sometimes even in scientific universities, these topics are taken for granted. Our project tries to overcome many of these issues with IBSE methodology and informal learning. Inquiry-based education in learning physics allows students to elaborate some topics more deeply and to understand and truly internalise concepts. It can be an opportunity for teachers too. They can try a different methodology and approach to the subjects with students and they can challenge themselves in creating new contents and a new way of presenting the topics. Moreover, the need to find new stimuli to make school education effective has emerged in recent years. Particular attention is devoted to scientific subjects, such as physics. Many informal proposals aim to bring young people closer to scientific disciplines, such as the project "The Show of Physics" [10-12] for science communication through scientific theatre of "La Statale" University of Milan. The project has so far realised seven scientific

plays for the general public and for students attending primary, secondary, high school and has reached more than 150000 people. By some research on audience opinion about physics before and after attending a play, the important role emerged of informal activities in students motivation to study physics [12]. It is known that informal activities are effective in school education, but it is often difficult to integrate them in a coherent formal didactic path. The purpose of the project described in this work is to create a didactic tool to use the informal elements presented in a theatre play in a formal environment. To achieve our educational goal, for our project we chose the IBSE methodology which encourages students to spontaneously ask questions, arousing their curiosity and, at the same time, making them active in their learning process. We intended to create a formal inquiry-based [13] educational path on electromagnetic radiations, for 12th or 13th grade students. We used the science theatre play, "Light from the stars"([1]), that deals with electromagnetic radiation and multispectral observation of the universe, in particular with visible, near-infrared, and ultraviolet radiation. The show also drives the audience's attention on some dangers of popular science and tries to awaken viewers' critical thinking. It invites the audience to pay attention and to verify what has been said on the stage, even when the speakers are scientists.

2. – The formal inquiry-based learning path

Our project is a formal inquiry-based learning path divided into three different activities. Each activity deals with a physical topic, inspired by the play "Light from the stars". They are described in the following:

- 1st "What do human eyes see?": the activities concerning this topic deal with visible radiation, its interaction with matter (*i.e.*, diffusion and absorption), the vision model, the physics of colours, additive and subtractive mixing, and eye physiology.
- 2nd "Seeing with different eyes": the activities deal with the electromagnetic spectrum, especially near-infrared and ultraviolet radiations, the ones closest to the visible range of the spectrum. It introduces spectral interaction coefficients: absorbance, reflectance, transmittance, their mutual relations and spectra, and some radiometric quantities, such as radiation intensity.
- 3rd "Emission and Spectra": the subject deals with far infrared, namely thermal radiation, laws of thermology (Stefan-Boltzmann law and Wien displacement law), heat transfer, and the qualitative behaviour of a black body.

Certain topics have been chosen as they are related to some conceptual issues, which the activities aim to clarify. Each activity consists of engaging parts, laboratory experiments, short videos, observation of phenomena, hypothesis making and model construction, and convalidation. Students can work in small groups independently and are free to think, and test their theories and models, and reject them when not fully explanatory. They can experience on their own the scientific method and the importance of comparison and discussion of results. The 2020 COVID-19 emergency required activities accessible for homebound students and teachers. In order to satisfy the emerging needs, we adapted our learning path to be performed online, and this also applies to the laboratory parts.

([1]) Italian title: "Luce dalle Stelle".

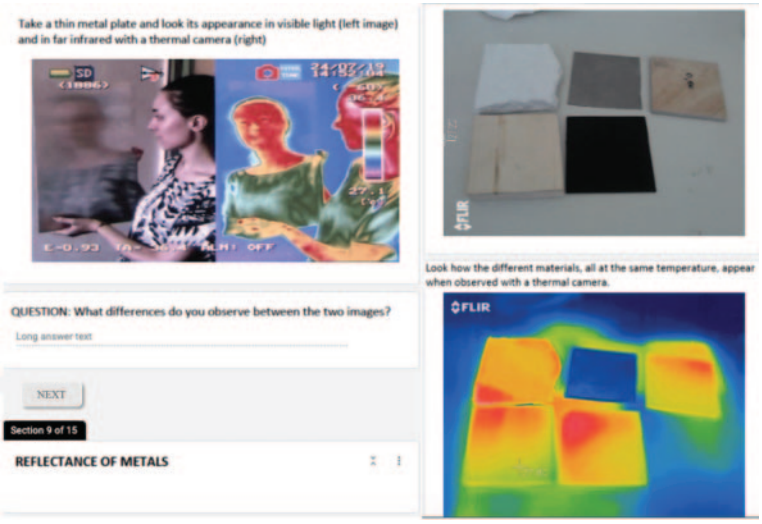

Fig. 1. – Examples of online pages of activity III that aim to introduce students to reflectance and emissivity of matter, starting from the counterintuitive case of metals. On the left, a person close to a metal plate, is shot in visible (left) and far-infrared (right) radiation. In the following form page (right), there is a second set of pictures, which show the visible (top) and thermal (bottom) images of different materials all at the same temperature.

We developed an online inquiry-based educational path that consists of six online editable Google forms, two for each main topic. Each form has a similar scaffold, it has questions, experiments to be performed by the students, sometimes with the help of online applications, brief theoretical explanations, images, and videos, many of which come from the play "Light from the Stars". The new online activities require even more independent work from students compared to the laboratory ones. In online forms, students can think and answer questions and find out how some phenomena work. They have the chance to directly observe physical phenomena and practice, or see, some experiments. Then, they are asked to think about possible laws and models. A typical form page that students face during the activity is represented in fig. 1. The didactical path has been refined in spring 2020, thanks to the suggestions of some university students, who tested the activities while attending a course on preparation of didactical experiences. It became clear that, when students use the online approach, teachers have to play a key role in guiding them through the various steps, more than in the laboratory case. They have to stimulate discussion among students on their questions and issues and to foster their understanding. Therefore, a guide addressed to teachers has been developed to conduct them through the online activity. The guide suggests teachers how to help students to overcome some conceptual issues that emerged from the pilot test with university students. It provides also advice about the critical points in the activities, such as the way to start a class discussion and the solutions to the proposed problems.

3. – Results and conclusion

The activity was used in autumn 2020 with about 40 high school students together with their teachers. It was presented to them as a curricular activity, split into six-afternoon sessions. First, the students received a Google link to the form, so they could fill it autonomously. Then we met them on an online platform and posed them new questions

and debated about the issues they had found. Furthermore, we remotely showed them other experiments and gave hints to test their knowledge. The experimentation gave positive results. Many students were active, responsive, interested, and curious about the topics covered in the activities. One student even made a final consideration of his/her knowledge built during the activity. He/she said to have suddenly realised that the more you learn, the more aspects you notice even in simple phenomena. We tested the students' appreciation with an anonymous questionnaire. Although the majority of students would have preferred an activity performed in the classroom and laboratory, they were satisfied after all. Students mainly appreciated the teaching method used, namely the inquiry-based methodology but also the fact that they could directly experience the scientific research method which allowed them to have a taste of the real physics research. Students particularly appreciated the use of images, videos, and online applications, thanks to which they better understood the topics and the concepts. Some students became curious about seeing the theatrical play, others appreciated the engaging part of the activities, different from the school approach to the subject. More than one-half of the students stated that their opinion of physics has changed in a positive way. The laboratory gave them a better understanding of electromagnetism, a new perception of physics, and a new way to deal with the subject. One student stated that during the laboratory he approached physics, quoting from the questionnaire, "with participation and not with anxiety and resignation". Another student, in particular, surprised us by saying that this experience made them see what real physics is. The approach was compared to a visit to a museum, instead of the study of paintings in a book, or to a trip in a foreign country instead of a geography class. In conclusion, remote learning can be inquiry-based with the right tools and with the teachers' awareness of students' issues and difficulties and the competencies to manage remote activities maintaining an inquiry learning perspective.

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