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Climate change: The physical basis of radiative phenomena for the study of the greenhouse effect

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Summary. — Effective teaching of the physical basis of the greenhouse effect is an essential element in understanding society's role in altering the radiative balances that are leading to current climate change. The results of recent research in this field show that two key concepts for its understanding are still incompletely learned by students. These concepts are the thermal emission of bodies, and the interaction of electromagnetic radiation (at various frequencies) with different materials. In this paper we present some experiments to facilitate the learning of these concepts and their integration within an existing teaching-learning sequence focused on the physical basis of the greenhouse effect. The results of this experimentation will also be illustrated and compared with previous proposals.

1. – Introduction

Climate change (CC) and more specifically the (anomalous) greenhouse effect (GHE) is becoming an increasingly topical issue [1] and of strategic importance to students as future citizens and rulers [2]. As a result, understanding the physical basis of this phenomenon has become an integral part of the curricula of Italian schools of different grades in different subjects: "Science" and "Technology" in K6–K8; "Natural Science," "Physics," "Integrated Science" and "Geo-history" in K9–K13; and more generally "Educazione Civica" (Civic Education) in all secondary grades. For this reason, we decided to modify a previous teaching-learning sequence (TLS) on GHE [3], and will present in this paper the teaching choices we made for the redesign. In particular, the focus has been on better understanding radiative phenomena related to GHE.

2. – Methodological framework

In designing the sequence, the model of educational reconstruction (MER) [4] approach was used, which involves three work plans: a) clarification and analysis of science content, b) research on teaching and learning, c) design and evaluation of teaching and learning environments. First, we focused on analyses of textbooks dealing with the topic [3] and drawings produced by our students during previous TLS trials [5]. From them, it emerged that the role of the following concepts is central to understanding the physical basis of GHE:

– thermal emission of electromagnetic (EM) radiation from a body and dependence of the spectrum on its temperature;

– selectivity of the interaction of EM radiation with matter and its dependence on frequency of incident radiation, type of interacting matter; and, in particular, the selective transparency exhibited by our atmosphere [6].

Similar difficulties also appear in the literature [7, 8] and in the analysis of the educational interventions previously conducted by our research group (both in the pre and in the post tests). In fact, summarizing what emerges in ref. [3] we have that:

– only 13% of students in the pre-test consider the selectivity of transparency (85% in the post-test), answering to the question *"What does it mean that a body is transparent?"*;

– only 5% of students report in the pre-test at least absorption (90% in the post-test), answering to the question *"Which phenomena can be observed in the passage of a ray of light through a container filled with water?"*;

– 61% of students talk in the pre-test about heat transfer by radiation (93% in the post-test), answering to the question *"An object, having a certain temperature T, is placed in a vacuum. How does its temperature evolve over time?"*.

Consequently, it was decided to focus redesign interventions precisely on these areas, in accordance with the cyclical approach to the sequence design shown in ref. [9].

3. – Research questions

The research questions that guided this work are:

–*RQ1*: Can the understanding of complex concepts such as thermal emission and selective transparency be improved using simple laboratory experiments?

–*RQ2*: How can the introduction of these experimens into a TLS improve understanding of a complex phenomenon such as the GHE?

4. – TLS design

The TLS redesign involved action on two levels: the *first one* regards conceptual map; it was revised in order to organize the content in a more consequential way (RQ1); *the second one* regards the experiments, which were redesigned to respond to RQ2.

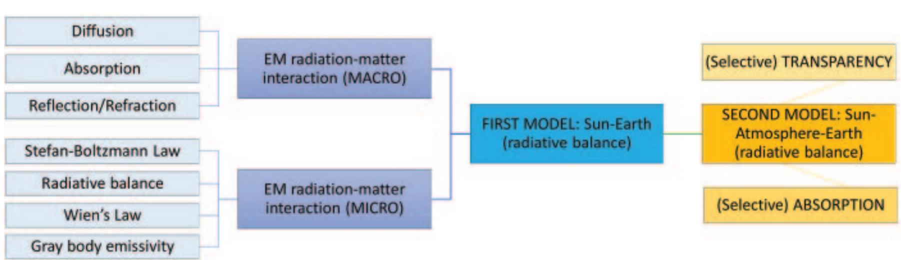

Fig. 1. – New structure of the teaching sequence. In blue the naive model and its key elements representing the TLS steps, in yellow the second model.

Fig. 2. – Experimental testing of Beer's law with dependence on the thickness of medium passed through. In the previous version (left image) of the experiment: the source of radiation is a lamp (visible); the measuring instrument is the smartphone brightness sensor; the medium of increasing thickness to be passed through are rectangles of paper sheets in increasing numbers. In addition to that part of the experiment, a measure is also carried out with a FLIR thermal imaging camera (centre image): the source of Infrared (IR) radiation is Leslie's cube; the measuring instrument is the FLIR camera; the medium of increasing thickness to pass through are rectangles of transparent plastic sheets. It is obtained (left image) that even in the IR the normalized intensity trend follows Beer's law. This experiment could strengthen the understanding of the concept of selective absorption.

4˙1. *Structure of the TLS*. – Figure 1 shows the new schematic representation of the sequence. It involves the creation of two models for climate. The first "naive" one takes into account only the radiative budget between the Earth and the Sun, without the presence of the atmosphere; in this model the role of the interaction of EM radiation with matter (both from the microscopic and macroscopic point of view) is central. The second adds in the balance the presence of the atmosphere and its selective absorption and transmission (depending on the wavelength of the incident radiation).

4˙2. *Experiments update*. – In the re-designed sequence, changes were made not only to the structure but also to the experiments when compared with the previous TLS [3]. The purpose of these changes is to achieve an improved understanding of the key concepts illustrated above. For this reason, some experiments have been updated (see an example in fig. 2) and some new ones have been added (see an example in fig. 3). In addition, to reinforce the concept of selectivity, the FLIR thermal imaging camera was integrated into several experiments (as can be seen, for example, in figs. 2, 3 and 4).

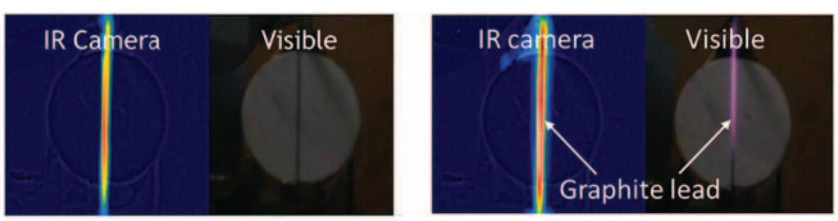

Fig. 3. – Glowing lead experiment, which is carried out to introduce Wien's law. The lead is inserted in series in an electric circuit in which the flowing current is gradually increased. As the current increases, the temperature of the lead increases. It is observed with the FLIR camera that for low currents there is emission of EM radiation in the IR spectrum (images with "IR Camera" label), but not in the visible spectrum (images with "Visible" label); while increasing the current we can see emission in both spectra. This experiment could improve the understanding of thermal emission and its dependence on body temperature.

Fig. 4. – Transmission selectivity. The use of the FLIR thermal imaging camera expands the concept of transparency, introducing that of selectivity (dependence on incident radiation and the medium passed through) and decoupling it from the idea of "transparent=if you can see through."

5. – Conclusion

The educational intervention of the new TLS has not yet been attended by statistically significant numbers of students, so quantitative analyses are not available. However, qualitatively, we found that:

– it was effective in improving understanding of key concepts about thermal radiation and the interaction of EM radiation with matter;

– this improved effectiveness has increased the understanding of the whole GHE phenomenon and, most importantly, of the role of humans in CC (responsible for the increase in greenhouse gas concentrations over the past two centuries).

In the future, it is planned to test the new sequence on a statistically more significant number of students (not only university, but also high school students) and to create training courses for teachers as part of the teaching of GHE in Italian schools.

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