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Civic scientific literacy: A teaching learning sequence on the climate change

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Summary. — The lack of adequate scientific knowledge can greatly affect citizens' choices, with serious consequences for the social capability to face main global challenges such as climate change. Scientific Civic Education (SCE) has to play a central role in the school of the future decades. We will discuss redesigning a Teaching Learning Sequence (TLS) on the physical bases of the greenhouse effect (GHE) in which the restructuring has been aimed at combining the disciplinary aspects with the most typical themes of the SCE and the perception of science. We report the results of some tests with students at different levels of education and the relationships between scientific knowledge and civic awareness will be focused.

1. – Introduction

Climate change is an important topic for students as future decision makers and citizens [1]. To be effectively active in the future, students have to recognize the scientific basis of this phenomenon. Thus "Effective public education on global warming... is essential" [2] and accurate knowledge is a "fundamental component" of responses to environmental issues. The civic scientific literacy is inserted in this context. It differs from traditional civic literacy as its purpose is to involve technical-scientific disciplinary fields, in order to educate to a participatory aware and responsible citizenship. In 2019, civic education was reintroduced in Italian secondary school (middle and high school). The legislation in this regard provides three conceptual nuclei, one of which is sustainable development, which takes up the objectives of the UN 2030 Agenda. In this paper we investigate the effectiveness of a TLS, designed by our research group, in favouring learning of the physical basis of greenhouse effect and global warming and in supporting the civic awareness about climate change.

2. – Methodological framework

The approach we followed in the designing of TLS is based on the "design, implementation, evaluation and redesign cycle" proposed in ref. [3] and revised on the basis of Design-Based Research (DBR) [4, 5].

The elaboration of the TLS was focused on two viewpoints: the iterative work where the results and products of the sequences already present in literature [6-10] were taken and re-designed, both in contents and in methodologies; the adaptive work, where it was needed to change the target and the focus to move from university students to middle and high school students.

3. – TLS design

3˙1. *Educational context*. – The TLS is suitable both for high school and undergraduate students and was tested with 30 undergraduate students in a laboratory course of the master degree in Mathematics and in Physics at the University of Trento, devoted to future physics teachers, and 50 high school students (grade K10 in a technical high school and K13 in a scientific high school).

3˙2. *Sequence of cognitive steps*. – The introduction of a complex issue requires a *progressive conceptual construction*, which implies the definition of a sequence of cognitive steps (*learning goals*) necessary to attain a coherent explanation of the GHE: to recognize and explain a *stationary condition of temperature* for objects exposed to the Sun or a lamp (energy balance); to *differentiate heat and radiation* and recognize that objects emit thermal radiation; to differentiate *visible and infrared radiation* and the behaviour of a material for different kinds of radiation; to put together the previous elements in order to understand *the radiative greenhouse effect in a 2-layer model* [8]; to understand the *greenhouse effect* on the Earth and the global warming starting from *a model of energy fluxes* developed for the 2-layer model, where the energy flows between the Sun, the atmosphere and the Earth can be expressed in a more formal way and the role of atmosphere absorption has been considered (the two layers exchange energy in the form of radiation, reflection, absorption, and re-emission, and the wavelength dependence is taken into account).

3˙3. *Students' difficulties*. – In the last two decades, several studies have investigated the students understanding of the greenhouse effect and global warming at different levels, highlighting that the knowledge of the subject and the correct explanation of these phenomena and processes is still limited and that difficulties in understanding are detectable in a transversal way at different ages and levels of education [6, 11, 12].

The results of the trial of the pilot test of the TLS [3] carried out in the same laboratory course, during the previous years, demonstrated that the students: do not take into adequate account the phenomenon of the emission of IR radiation; tend to attribute an absolute meaning to optical properties, without considering the dependence on wavelength; tend to confuse transient phases (in which the temperature changes) with stationary phases; encounter great difficulties when considering the interdependence of all the factors and phenomena involved in the energy balance.

By proposing the questions contained in well-known concept inventories to numerous students, further information on their ideas is gained. For example, Keller [11] identified the following: explanation of the GHE as an increase in incoming solar radiation and a decrease in the outgoing flow; mixture of concepts associated with the GHE, global warming and the ozone hole; belief that solar radiation peaks at the ultraviolet; trapping models, involving permanent trapping of the radiation, trapping through reflection and gas and pollution trapping; the concept that the Earth's surface radiates energy mainly during the night.

3˙4. *Didactic choices*. – Fundamental decisions regarding the design of the TLS are: propose activities based on a combination of real experiments and interactive simulations; propose quantitative experiments followed by an accurate data analysis; use smartphone camera and sensors in the experiments according to the BYOD approach; let students perform the experimental and modelling activities in small groups (they are guided through carefully sequenced activities to make observations that they can use as the basis for their models).

Thus the experimental activity is the core of the sequence. Furthermore, the emergency due to the pandemic had to be faced. For this purpose, the experiments, usually performed with students in a physics laboratory, had to be performed remotely by students on their own. We provided students with a home kit (designed and developed in the COSID-20 project of the University of Trento) which includes laboratory instruments and equipment.

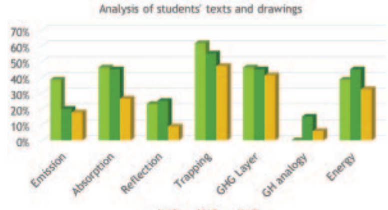
The experimental activities provided for the TLS concern: geometric optics; Beer's law (absorption) carried out with smartphone brightness sensor; selective infrared transparency using a FLIR thermal camera (in order to make students aware that transparency is selective, depending on the wavelength); Stefan-Boltzmann's law (found out in a experiment with a light bulb) and dependence of the spectrum on temperature; achievement of radiative equilibrium for a metal plate exposed to radiation. The experimental activities were complemented by PHET simulations on Beer's law and radiation-matter interaction. Finally, two theoretical models have been developed: the first one on the radiative equilibrium, the second one the two-layer approach [3].

4. – Results

Data from pre- and post-tests show a significant gain in all the conceptual areas involved in the sequence and particularly in understanding the interaction mechanisms between radiation and matter. Drawings, produced by students before and after the sequence, allow to identify the evolution from common representations of the greenhouse effect, based on the idea of multiple reflections and trapping, to simple but scientifically correct descriptions based on energy flows and balance.

Figure 1(left) shows the result of the analysis of the drawings and texts produced by the students: we looked for the presence of any students' misconceptions (*i.e.*, searching for representation of multiple-reflection rays, GHG layer, rays trapping, Earth emission, atmospheric absorption, etc.) and found a similar trend at all school levels (and in line with what was found in the literature) [13].

In fig. 1(right) we make a comparison between the results (before and after the educational intervention) regarding the question "How worried, if at all, are you about climate



How worried, if at all, are you about climate change?

	EPCC 3	K13-PRE	K13-POST	K10-PRE	K10-POST
Average:	2,99	3,62	4,00	3,49	3,56
St. Dev:	1,07	0,76	0,67	0,99	0,92
Gain:			28%		5%
Moda:	3	3	4	3	4
1	10%	0%	0%	1%	2%
2	19%	4%	0%	13%	8%
3	41%	44%	22%	41%	35%
4	22%	40%	57%	26%	40%
5	8%	13%	22%	19%	17%

1 Not al all worried
2 Not very worried
3 Fairly worried
4 Very worried
5 Extremely worried

$$\text{Gain} = \frac{\langle post \rangle - \langle pre \rangle}{5 - \langle pre \rangle}$$

Fig. 1. – (Left) Analysis of students' texts and drawings answering the pre-test question: "Considering radiation coming from the Sun, make a drawing that explains the greenhouse effect, adding some explanations that helps to interpret your representation". (Right) Students' concern by climate change (K13: scientific high school; K10: technical high school; PRE: before educational intervention; POST: after educational intervention).

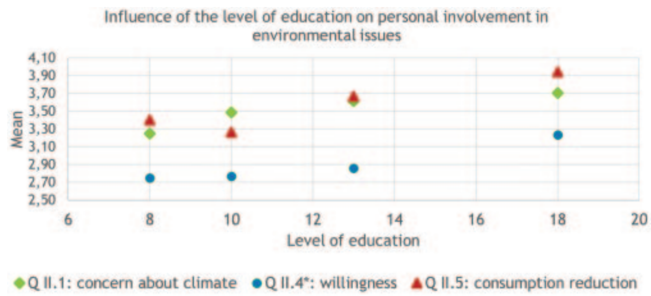


Fig. 2. – Influence of the education level on personal involvement in environmental issues. The number on the abscissa indicates the years attended, included the last in progress.

change?". It comes to light that all interviewed high school students have a greater concern than the EPCC reference sample [13]; moreover, for 18-year-olds there is a further significant increase after the course has been completed.

The results obtained on the three following questions have been compared in fig. 2: the first question is about climate concerns; the second one concerns the willingness to actively participate in the mitigation of climate change; the last regards the willingness to significantly decrease energy consumption in order to reduce emissions.

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