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Climate change: an educational proposal integrating the physical and social sciences

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Abstract

The scientific community has been debating climate change for at least twenty years. The EU has recommended a set of innovative reforms to science teaching, incorporating environmental issues in the scientific curriculum, answering the need for making school a place of civic education.
This paper focuses on the presentation of materials designed to foster both deep understanding of the basic concepts involved in climate change as well as critical thinking for addressing some cognitive and emotional barriers that have been proved to hinder individual behavioural reactions.

Keywords: Climate change, Science Education, Behavioural Science, Educational Reconstruction;

1. Introduction: state of art and purpose of the study

The complexity related to environmental issues and to the rapid climate change occurred in the last decades is one focus of attention of the EU cultural politics. Emblematically, it is at the heart of a fundamental Societal Challenge of Horizon 2020, where it is claimed: "*There is incomplete knowledge on the ability of society and the economy to adapt to climate change. Effective, equitable and socially acceptable measures towards a climate resilient environment and society require the integrated analysis of current and future impacts, vulnerabilities, population exposure, risks, costs and opportunities associated with climate change and variability, taking into account extreme events and related climate-induced hazards and their recurrence.*" (Horizon 2020, *Ibidem*, 5.1.2).

In the last 10 years the EU has being recommending a set of innovative reforms for science teaching, incorporating environmental issues in the scientific curriculum, answering the need for making school a place of civic education. Currently, as Osborne and Dillon claim, there is little emphasis within the science curriculum on discussion or analysis of environmental issues (Osborne & Dillon, 2008).

Educational proposals on climate change are being developed in different research fields among which Science Education and Social and Behavioural Sciences. These two fields have specific aims, their own languages and

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research problems. Science education researchers and instructors primarily aim to enable students to understand scientific concepts. Meanwhile, behavioural scientists aim to understand how to foster energy-saving and generally pro-environmental behaviour.

More specifically, within Science Education Research, important studies have investigated the difficulties in explaining the greenhouse effect to students. The main results highlight that the crucial physics concepts involved in understanding the greenhouse effect (i.e. absorption, transparency, black body) are usually treated superficially, both from textbooks and from teachers (Besson *et al.*, 2010). Still, the traditional organization of scientific content in theories (i.e. thermodynamics, optics) is said to create barriers in understanding the greenhouse effect which is a typically intra-disciplinary issue (Besson *et al.*, 2010). Because environmental issues, such as global warming, have proved to be an engaging context for motivating students, several scholars suggest to introduce them to enable students to learn more and better physics and/or for discussing general topics, like the role of modelling and visualization (Svihla & Linn, 2011).

On the other hand, within the Social and Behavioural sciences, a demanding research problem under investigation is why citizens are so resistant to getting involved in the climate change issue.

The comparison of the results produced in the two fields points out a sort of paradox: environmental issues are intellectually stimulating for learning science, but seem to be not enough for fostering a behavioural change.

The question about the effects of knowledge on pro-environmental behaviour is not extensively discussed within Science Education research, whilst it is vigorously discussed within Behavioural Sciences. In this field some scholars tend to put much emphasis on the potential of understanding to engender changes in behaviour (Reynolds *et al.*, 2010; Read *et al.*, 1994), while on the other hand others suggest that increasing the amount of relevant information surrounding an action does not imply that this action will be automatically performed (Leiserowitz *et al.*, 2010). While knowledge is often portrayed as an ineffective driver of human action (Norgaard, 2009; Immerwahr, 1999), seldom is it asked which kind of knowledge constitutes the "the first step" toward a behavioural reaction in the field of climate change. Two kinds of knowledge seem to be fundamental: the understanding about basic causal dynamics that lead to climate change, since if one does not realize how and why greenhouse gases are responsible for global warming, they will not even think about reducing CO_2 emissions (Pongiglione, 2012), and *procedural* knowledge, i.e., practical and locally contextualized information that helps individual translate personal beliefs regarding climate change into concrete action (Kaiser & Fuhrer, 2003).

The main goal of our project is to propose and design teaching experiments where students are involved in learning activities based on a specific "educational reconstruction" of content knowledge (Kattmann *et al.*, 1996). More specifically, the reconstruction has been designed to foster, simultaneously, deep understanding of scientific knowledge and critical thinking about personal behaviours. An additional goal is to study if and how the complexity of global problems can be managed by secondary school students, and also be transformed into a productive resource for engagement, deep understanding and acknowledgment of science as cultural heritage of society (Levrini *et al.* 2013, *submitted*).

Data on students' reactions to the materials are collected and preliminarily analyzed in order to identify the type and the level of knowledge needed, and, ultimately, to plan an experiment in a real classroom context. This paper focuses on the presentation and discussion of the designed materials: the phases of the design, the design criteria and the content organization.

2. Methods and findings

The research study carried out so far has been divided into three parts:

- the identification of the main cognitive barriers that prevent individuals from engaging in pro-environmental actions (§ 2.1);
- the identification of operational criteria for rethinking the disciplinary content arising from the analysis of barriers (§ 2.2);
- the application of those criteria to simple models of explanation of global warming, extended to more general climate change, and the design of a content reconstruction developed into 5 phases (§ 2.3).

2.1. Identification of the barriers

Research in the social sciences has suggested that citizens' resistance to getting involved in the climate change issue is to some extent due to some intrinsic features of environmental problems, that obstruct the proper reaction to it. The literature in behavioural science suggests three main barriers that hinder personal involvement:

a) *Not individual but collective* - climate change is not perceived as an individual problem, but rather as a collective one; for this reason the subject feels justified for his inaction, and tends to believe that only major actors can significantly prevent it (Eurobarometer, 2011; 2009). The individual does not perceive his interaction with the natural world, nor his own role as causal agent in the climate change issue (Pongiglione, 2012);
b) *Too big or too small* - scarce knowledge of climate change effects cause also its risks to appear to the individual as either too small, and irrelevant for the everyday life of people (Leiserowitz, 2006), or too big, such that the individual feels completely helpless in front of them and prefers to ignore the problem in order to avoid feelings of fear, guilt and hopelessness (Norgaard, 2009).
c) *Too far* - The climate change issue is seen as a distant problem, that will not affect the current generation and can thus be ignored (Lorenzoni *et al.*, 2007). It is in general difficult for people to deal with long term problems (Oppenheimer & Todorow, 2006), especially if they require individuals to "pay" in the short term for a possible benefit of the future generations.

2.2. Definition of operational criteria for disciplinary reconstruction

Looking at the identified barriers, three operational criteria have been pointed out to guide the process of discipline reconstruction that can allow science education to address them:

a) explaining the role of the individual and his interaction with nature in the modelling of global warming (barrier a).
b) including, in the discussion of climate change, examples of causal connections, typical of complex systems, between man-nature-technology, and examples of feedback to show that small causes can have large effects and *vice versa* (barrier b).
c) placing the examples already treated on a time scale, typical of an evolutionary approach to complex systems, to reflect on possible future scenarios (i.e. the melting ice) (barrier c).

2.3. Design of the content reconstruction

These criteria led us to rethink disciplinary contents and to build a multi-disciplinary path. The design of the content reconstruction was divided into 5 phases.

The aim of *Phase 1* is to stress what is shared by the scientific community (the increase of temperature of the Earth surface) and to provide examples of controversial issues. The design foresees the presentation and discussion of examples of some shared and controversial points taken by the IPCC report. In particular, it is stressed that warming of the climate system is unequivocal, that global warming is very likely [90%] due to anthropogenic causes of greenhouse gases increases and that the origin of many controversies is the intrinsic difficulty in producing mathematical and physical models able to take into account a huge number of variables. A crucial point of this phase is the introduction of the notion of a feedback mechanism, that is a new way of reasoning with respect to classical physics and a typical way of reasoning in complex systems, like the climatic system.

Phases 2-3 are designed to be two laboratory sessions characterized by the methodological choice of designing and implementing activities aimed at triggering peer-to-peer interaction, encouraging students to play with their ideas and giving examples of how to move from models to experiments and *vice versa*. In these two phases the relevance of the physics hypothesis in the game of modelling is highlighted, in particular the significance of the relation between the composition of the atmosphere and the increase of the Earth's temperature surface. These are crucial points that express the core of the reconstruction.

More specifically, *Phase 2* focuses on experiments on interaction between radiation and matter. The aim is to revise and construct the basic physics concepts needed to explain the greenhouse effect. In particular, the concepts of absorbance (a), reflectance (r) and transmittance (t), as well as the Stefan-Boltzmann law and Kirchhoff's law are analyzed in detail. In dealing with these concepts, it is emphasized that: *a-r-t* are properties which describe the interaction between matter and radiation; all bodies emit according to their temperature; in stationary condition there is a balance between the incoming and the out-coming energy. Fundamental steps of this phase are to construct the phenomenological relation between absorbance of a body and its temperature and to stress absorbance as the crucial property for interpreting the thermal effects of radiation.

The aim of *Phase 3* is to guide students to construct a model of a "greenhouse", which can explain why and how a change in atmospheric composition can produce temperature rise on the Earth's surface. A very simple model is chosen based on a set of essential hypotheses, including: the Earth is modelled as a black body; the atmosphere is modelled as a uniform and homogeneous layer (metaphorically imaged like a sheet of plastic); radiation is assumed constant and average only on two wavelengths, in particular short waves for incoming and long wave for the outgoing; and the absorbance of the atmosphere is different according to the two wavelengths. In spite of these simplifications the model appears to be suitable to enable students to get acquainted with reasoning in terms of energy balance and to understand, through some steps, the formal relation between atmosphere absorbance and earth surface temperature (Besson *et al*. 2010).

The significance and the power of this model is that it strongly and directly stresses that if the absorbance of the atmosphere (for long wave radiation) increases, then the Earth's surface and atmospheric temperature increase in order to keep the balance with the incoming radiation. This relation between absorbance and temperature has several implications. One is that absorbance can be interpreted as the bridge between anthropogenic causes (i.e. greenhouse gasses emissions) and the physical explanation of global warming (Barrier a). Another implication of that relation is the opportunity it gives to exemplify, by means of physical phenomena, like the melting ices, the concept of a feedback mechanism: the melting ice causes an increase of water vapour, carbon dioxide and methane gas (that are some of the major greenhouse gasses), so their emission in the atmosphere causes an increase of absorbance that in turn causes an increase of temperature (example of circular causality, so that causes and effects cannot be clearly distinguished).

The aim of *Phase 4* is to introduce some concepts typical of the paradigm of complexity so as to refine the epistemological discourse and to address, from a new perspective, the behavioural barriers. In particular the notion of feedback is re-analysed to stress the epistemological distinction between linear and circular causality, previously introduced, where circular causality means that: i) causes and effects cannot be clearly distinguished; ii) small changes, in space and time, can produce big changes (Barrier b). Moreover, the concepts of time evolution, self-organization and multiplicity are introduced in order to discuss the notion of predictive power of a model and to stress that, in complex systems, the space-time scale of self-organization is different from the single sub-systems ones. Finally, the simple model of Schelling about social segregation is illustrated to analyze the relation between a system and its sub-parts in an example concerning the relation between individuals and society and to stress, again, that small (individual) changes can produce big social effects.

Phase 5 provides a framework on political and economic scenarios related to climate change and to illustrate the water and carbon footprint of common habits and daily activity, along with details on energy consumption of households appliances. The aim of this Phase is twofold: on a one hand, it is crucial for students to understand the role of international climate agreements, and to acquire some knowledge about the current developments towards a global treatise on emission caps. On the other hands, students need to understand that not only policy makers have the power to influence the situation, but also citizens, that with their daily behaviour and habits have the ability to contribute significantly to climate change mitigation.

3. Findings and conclusion

The role of the process of modelling, differently and specifically addressed in each phases, represents the core of the disciplinary reconstruction (Levrini & diSessa, 2008). In particular, the model used for explaining the greenhouse effect, in spite of its simplicity, has epistemological, cultural and learning potentials which are progressively emphasised throughout the teaching path:

- it is based on an energy balance reasoning and not on the wide-spread and misleading idea of "trapping", according to what is suggested by the more advanced studies in Physics and Physics Education;

- it provides an opportunity for re-analyzing basic concepts from a physical, intra-disciplinary perspective which overcomes barriers between disciplinary areas (Optics, Thermodynamics, Electromagnetism);
- it can be progressively constructed through a back and forth dynamics between theoretical hypothesis and exploration of the phenomenology, according to an Inquiry Based Approach (Fazio *et al.*, 2008; Marx *et al.*, 2004).

Moreover, the model implements, partially but explicitly, the operational criteria pointed out in order to overcome the identified behavioural barriers. In fact, the model allows to recognize the central role of human action in the variation of absorbance of the atmosphere (parameter *a*) (Barrier a), to provide the opportunity to discuss examples of feedback mechanisms and circular causality (Barrier b), to pave the way to the introduction of the epistemological perspective of complexity and to the discussion of the time-evolution of complex systems (Barrier c).

A first level of analysis of the data, collected during a preliminary test of the designed materials, showed that the introduction of the epistemological perspective of complexity seems to be potentially able to provide students with the cultural tools to rationally navigate in the jungle of ideological wars about environmental issues.

Pulling the strings of the research study, the first results support the hypothesis that the kind of knowledge introduced and discussed with the students may provide a significant contribution to *i)* avoiding that the climate change issue is perceived by students as *generally* uncertain; *ii)* understanding which scientific dynamics within climate change still presents a certain level of uncertainty. This is a crucial point for perceiving science as a reliable source of knowledge, and important goals in the challenge of finding an effective perspective, not only for teaching Science, but also for educating young people to Scientific Citizenship and producing conscious behavioural changes.

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