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# Developing future-scaffolding skills through science education

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**ABSTRACT**

Can science teaching contribute to developing skills for managing uncertainty towards the future and projecting imagination forwards? If so, how? In this paper, we outline an approach to 'teach the future' through science education. In the first part, we describe a framework that has been constructed to orient the design of teaching modules comprised of future-oriented educational activities. Then, a teaching module on climate change is described. The module was tested in a class of upper secondary school in Italy (grade12) and the main results are reported. They concern a change in perception of the future, as revealed by students: from far and unimaginable, the future became conceivable as a set of possibilities, addressable through concrete actions and within their reach, in the sense that they became able to view themselves as agents of their own future. The results lead us to argue that the approach appears promising in developing 'futurescaffolding skills', skills that enable people to construct visions of the future that support possible ways of acting in the present with one's eye on the horizon.

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## Introduction

Among all the changes that the new generations have to face, one appears particularly worrying: the relationship of young people with time.

In this 'society of acceleration and of uncertainty' (Rosa, 2013), the young are coping with an unpredictable future and a past that fails to provide clues which can help them to interpret the current complex and changing world. Consequently, the present is lived as completely oriented toward seising the moment, sniffing out every opportunity, and keeping open all possible scenarios: a frantic standstill, perceived as 'dust of moving splinters', a plurality of events without real temporal connections between them (Leccardi, 2009). Without future and past, and with an extended and fragmented sense of present, young people are commonly experiencing an alarming loss of sense and hope, a new form of nihilism that creates a sense of huge distance between their actions and the places, events and institutions that can really influence their plans or life projects (Benasayag & Schmit, 2006).

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Such a situation challenges sociologists, policy-makers, psychologists, entrepreneurs and societal stakeholders in general, since this suffering of the young with time touches the heart and future of our societies. Among all the stakeholders, scientists and researchers in science education are particularly invested, since crucial causes of the increasing loss of hope regard issues like climate change, where science and science education play a crucial role.

This global situation raises and poses three demanding questions to researchers in science education:

(i) can science teaching contribute to developing skills for managing (rationally and emotionally) uncertainty towards the future and for projecting imagination forwards? If so, how?
(ii) how can science teaching provide students with opportunities to experience the present as a real moment of world comprehension, sense-making and self-construction?
(iii) how can science teaching foster the development of a dialogue with a past able to grasp and interpret the present?

In this paper, we present the approach we are developing to address the first question. Our approach conceptualises future as a driver to guide actions in the present and ask questions of the past: if present and past without future are blind, it is also true then that future without present and past is useless, inert. In this light, the first question has been addressed with an eye on the second and third queries.

The approach is based on the analysis of a wide literature that, given the multidisciplinarity of the topic 'future', embraces several fields (including science, science education, epistemology, sociology, politics, and labour market). In the first part of the paper, we report the results of this analysis in the form of a three-pronged framework that shows how different domains (Science Education, Science and Society, Futures Studies) provide hints to infuse the dimension of future into science education (Bishop, 2010). The analysis results in the formulation of design principles that we employed in designing future-oriented school science materials.

Following this, we present a sample module on climate change, which we constructed according to the design principles. The module has been implemented with secondary school students. Although this paper is mainly theoretical, we report and discuss some results of the implementation to provide an idea of the impact of the module on students' perception of the future and on their ways to grapple with the issue of time.

In the paper, we refer merely to physics education since this is our specific area of research and the focal area of our first pilot study. However, the general argumentation can be extended to produce teaching modules on topics like Artificial Intelligence, Quantum Computing, Nanotechnologies, which integrate Science, Technology, Engineering and Mathematics (STEM) disciplines (Branchetti, 2018). Both the refinement of the approach and its application to multidisciplinary STEM topics are part of the European Project Erasmus+ I SEE 'Inclusive STEM Education to Enhance the capacity to aspire and to imagine future careers' that we are developing. The project and its main goals are discussed in the final part of the paper.

## Framing a possible approach: from a literature analysis to design principles

### *'The Future' as intrinsic to science*

The relation of science – and physics in particular – with the topic of the future is very strict: the future is intrinsic to science, due to prediction standing at the core of science modelling.

In physics classes at school, teaching insists – almost exclusively – on linear causal models built according to Newtonian physics which historically provided the mathematical models, language and epistemological scaffolding to view the future deterministically, as a linear progress towards an ever-better world. Science, however, throughout its history, has developed other temporal patterns and models of causal explanation, like those typical of quantum physics or of the so-called *science of complex systems,* which are at the basis of physical fields like atmospheric physics, geophysics, medical and bio-physics.

Science of complex systems is a wide and very technical field, but the sense of its causal, temporal and functional structures can be highlighted also at secondary school level, provided that basic concepts are introduced: the definition of complex system, the concepts of non-linearity, high sensitivity to initial conditions, feedback and self-organisation. The educational relevance and 'learnability' of these concepts have been the subject of important studies within science education and the learning sciences (e.g. Abrahamson & Wilensky, 2005a, 2005b; di Sessa, 2014; Duit & Komorek, 1997; Jacobson, 2000; 2001; Jacobson & Wilensky, 2006). Here, we re-consider them to stress how and why these concepts concur to offer knowledge and epistemic resources for imagining possible futures.

Even though sketching out a complete and univocal definition of *complex system* is an ambitious task (Gell-Mann, 1995), the scientific community tends to identify it in terms of the features and behaviours it displays (Cilliers, 2007). In general, a complex system consists of a set of individual elements (agents) which, interacting with each other according to non-linear relationships, provide the resulting complex system with some properties that classical systems do not have. The *non-linearity* – in the equations that describe the macroscopic variables of the system or in the rules for the behaviour of the agents – involves, for many complex systems, renouncing the proportionality between the magnitudes of causes and effects: this is the *high sensitivity to initial conditions*, also known as 'butterfly effect' (Lorenz, 1972) or deterministic chaos. Another consequence of the non-linear mathematical description of such complex systems is the change in the conception of causality that shifts from linear to circular: if A makes B happen, B is also a cause itself and can modulate or perpetuate A. Circular causality makes the concept of *feedback* fundamental for the study of complex systems: it can be defined as an element of the cause–effect relationship intended as a circular loop in which the last effect of the chain acts back on the cause from which the loop has started, amplifying it further (positive feedback) or softening it (negative feedback). Because of non-linearity, some complex systems, especially those consisting of a large number of elementary components, display global properties that cannot be deterministically ascribed to the rules which the individual agents obey but emerge from the *self-organisation* of the system, i.e. from the local interactions among agents and groups of agents (Ferrari & Chi, 1998; Wilensky & Resnick, 1999). From this perspective, also the reductionist paradigm typical of Newtonian physics loses significance: in complex systems, understanding the individual components is crucial but the knowledge of the parts is not sufficient to explain the behaviour of the whole system; the complex interactions between parts create new processes, functions and structures that, despite their material basis in the underlying components, are conceptually independent from them (Morin, 2001).

Based on these new concepts, the science of complex systems has laid the foundations for a new epistemology (Morin, 1986) in which a central role is assumed by the concept of uncertainty and by the new conception of causality. Within this epistemology, the vocabulary and schemas for talking and reasoning about the future are enriched. According to Newtonian and Laplacian deterministic conceptions, the present can be thought of as something deterministically dependent on the past while the future is viewed simply as the result of an ideal linear chain of events. In complex systems, deterministic prediction in a quasi-classical sense still works only within specific space–time scales, like those that characterise the models of weather forecasting. When the space–time scales are bigger, as in climate models, or there are too many variables, as in the models that also include anthropogenic, economic or socio-political elements, the deterministic chaos forces the classical notion of univocal prediction to give way to the concept of *projection* and a range of many possible futures, as wide and varied as the future *scenarios*. According to the glossary of the Intergovernmental Panel on Climate Change (IPCC), a *projection* 'can be regarded as any description of the future and the pathway leading to it' (http://www.ipcc-data.org/guidelines/pages/definitions.html). In this new vocabulary, a *forecast* or *prediction* is a projection that is branded 'most likely'. The range of uncertainty in projections is reflected in the set of possible scenarios, where a scenario is defined as:

> a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold. A projection may serve as the raw material for a scenario, but scenarios often require additional information (e.g. about baseline conditions). (http://www.ipcc-data.org/guidelines/pages/definitions.html)

All these concepts do not only problematise a linear, deterministic way to conceive the future: they also pave the way to a *world of possibilities* where the uncertainties are conceptualised and managed through rigorous and specific modelling tools (e.g. simulations). Because of these aspects, the science of complex systems is appropriate, in our opinion, for addressing the issue of future as it can be considered a source of conceptual and epistemological knowledge that can be converted into skills and inform students' approaches to complex and future-related issues, ranging from climate change to urban policies (Barelli, Branchetti, Tasquier, Albertazzi, & Levrini, 2018).

In the light of these remarks, the first set of design principles that characterise our teaching approach includes: (1.1) *making the scientific temporal patterns and causal models explicit, by introducing and discussing complex system concepts in appropriate (physics) curricular moments (for example, when the curriculum includes topics like thermodynamics or climate change)*; (1.2) *enabling students to have direct experience with the language and tools (e.g. simulations) of the science of complex systems and its societal implications, so as to turn scientific knowledge into skills to talk and think about the future (and, hence, about the present and past).*

### *'The Futures' as intrinsic to societal challenges*

The future is a relevant topic in science but of course it is not only limited to this field. Skills to grapple with the future are also included in the lists of *transversal* or *soft skills*[1] strongly requested by STEM-based industry leaders (The Economist Intelligence Unit Limited, 2014; Waterloo Global Science Initiative, 2014) or societal stakeholders (e.g. NGOs and policy-makers). Examples of required skills related to future include: *strategic thinking* and *planning*, *risk taking, possibilities thinking, managing uncertainty, creative thinking, modelling and argumentation,* and *project planning*. Within the field of science education, in the last two decades, interest in students' development of such skills has increased. According to Tidemand and Nielsen (2017),

> it has become paradigmatic for educational systems to shift the aim of science teaching from developing student knowledge to a more functional aim of developing students' competences – the abilities to solve complex problems by drawing on knowledge, values, skills, and attitudes that together make effective action possible. (p. 1)

The importance of exploiting the societal relevance of scientific contents is strongly stressed by the research on Socio-Scientific Issues (SSI) (Levinson, 2007; Sadler, Foulk, & Friedrichsen, 2017). SSI are controversial, ill-structured problems for which there is not a univocal correct answer, with solutions being uncertain and complex. Their multidisciplinary nature is a widely discussed topic (Morris, 2013), and they must incorporate two main elements: connections to science contents and social significance (Sadler, 2009). Examples of SSI are genetic engineering, climate change, or 'fat taxes' on 'unhealthy' foods. To make SSI teaching and learning effective, different models and frameworks have been developed. Sadler et al. (2017) proposed a model in which teachers and educators introduce and discuss SSI with students in three phases: encountering the focal issue, engaging with science ideas, science practices and socio-scientific reasoning practices; synthesising key ideas & practice. Throughout the teaching/learning process, students are encouraged to progressively develop their own positions on SSI and, to achieve this goal, they are helped to develop their scientific knowledge, as well as to consider social, economic, ethical, and moral aspects of the problem (Sadler, 2009).

Empirical results have shown that SSI are effective contexts for the development of knowledge and processes contributing to scientific literacy, including evidence-based argumentation, consensus building, moral reasoning, and understanding and application of science content knowledge (Sadler, 2009; Zeidler & Sadler, 2011). Nevertheless, some criticalities have been underlined: controversial issues need scientific knowledge and arguments that students are not used to dealing with (Levinson, 2007); the role of teachers in leading classroom discussions about such issues and maintaining each student's authentic voice is problematic, in particular when scientific arguments are invoked by the speakers (Nielsen, 2012) and when the criticalities of the dialectic authoritarian/democratic science emerge (Levinson, 2007); teachers have difficulties in operationalising complex competences and assessing them (Tidemand & Nielsen, 2017).

There are many similarities between the SSI approach and ours: our approach is also focused on the societal relevance of scientific contents; we remain aware of the critical aspects stressed in the SSI literature; we also choose topics like climate change which can lead to controversies; we discuss the social dimension and use decision-making open problems in order to leave room for students' values when discussing such choices (Levinson, 2007). However, there are also substantial differences, mainly because our approach is focused on a different problem. While SSI teaching methods mainly aim to contribute to the development of an 'ethical scientific citizenship', our target audience of young students is encouraged to develop skills to imagine possible and desirable futures and is guided to use such images of futures as a propulsive force in their life, in order to activate their resources, engage in societal challenges and orient their choices and action in the present. So, instead of controversial issues, we choose *future-relevant* focal issues, i.e. issues that have to include, at least, two elements: (i) connections to fundamental scientific contents and practices (patterns of reasoning, argumentation, explanation); (ii) future significance, in the sense that they have to represent a societal challenge widely debated also for its implications on the future. Examples of *future-relevant* scientific topics are climate change, artificial intelligence, big data and quantum computing. After a phase of encountering the focal issue, teaching activities are carried out to enable students to develop transversal skills and, thanks to these, engage with the future – social, environmental, economic but also personal – implications of the issue (Branchetti, 2018).

For example, the module on climate change includes activities for developing transversal skills of project planning. In this real case, we aimed to develop skills typical of Project Cycle Management (EC, 2004) for contingent reasons: the research group included an expert of this method and we have all personally experienced the effectiveness of this approach in developing and structuring future-oriented imagination. We now briefly describe the PCM methodology for two purposes: to exemplify what we mean by transversal future-oriented skills and to pave the way for introducing the module and specific activities we designed and implemented. Many other approaches or professional techniques can play the same or a similar role in developing this kind of skills.

PCM is an analytical and managerial tool, originally developed by NASA and then adopted by USAID (US Agency of International Development) in order to improve the process of project planning and evaluation. Currently, PCM is widely used by various international NGOs and within European programmes such as Horizon 2020 (https://ec.europa.eu/programmes/horizon2020/). PCM is grounded on Goal-Oriented Project Planning (GOPP) and the Logical Framework Approach (LFA).[2]

A *goal*-oriented planning approach has been developed as opposed to the more common practice of *strategy*-oriented planning. Unlike the latter, which focuses on strategies and resources, GOPP guides the designer to focus on the beneficiaries of a project and its objectives. GOPP, and its variant LFA, includes tools (e.g. matrixes) that encourage consistent distinction between: general objectives to which the project can provide a contribution; specific objectives that the project aims to reach; strategies or activities that the designer chooses to reach the objectives; and the operational means that the designer chooses to complete the activities. This distinction, if carefully implemented, allows designers to clarify the structure of a project and thus anticipate possible risks and alternative solutions.

The first stage of the project planning, as foreseen by GOPP and LFA, is 'problem setting', i.e. an analysis of the current situation and the construction of a 'problem tree': a causal map that highlights the relationships between the problems. A good problem tree is the basis to identify the objectives and their inner structure (the 'objective tree').

As we will describe in more detail in the next section, we valued the skills typical of project planning and enhanced by GOPP and LFA, as aids to fleshing out the inner (complex) causal structure of scientific discourse on climate change and to exploring the (non-linear) implications on future of mitigation and adaptation actions (possible scenarios).

Returning to the main argumentation flow, the second set of design principles includes: *integrating the societal and vocational dimensions* (Stuckey, Hofstein, Mamlok-Naaman, & Eilks, 2013) *with the conceptual and epistemological dimensions in science teaching. This implies, operationally, (2.1) the choice of a future-relevant scientific issue and (2.2) the design of teaching activities aimed at developing special transversal skills: skills helpful to mapping the complexity of the present into a comprehensive picture* and *engaging with the future significance of the issue.*

## 'The Futures' as intrinsic to the process of personal engagement

Thinking about the future implies that people – and the young, in particular – face and tackle their values, desires, irrational fears, and images of possible worlds. In this sense, the perception of the future involves personal engagement (Levrini, Fantini, Tasquier, Pecori, & Levin, 2015). An interdisciplinary field, named *Futures Studies (FS)*, has been investigating such a problem from a wide perspective. The FS community involves sociologists, philosophers, as well as STEM, economics, politics and entrepreneurship professionals.

The FS approach draws upon the science of complex systems and, consistently, questions the common belief that *futures are only matters of making predictions from the present towards,* instead stressing futures as ways to *open a fan of possibilities*, whose evolution follows (in the medium and long term) the non-linear dynamics of complex systems. Since accurate predictions are not necessary nor possible (due to scientific constraints), it is socially, economically and personally important to develop skills for thinking about possibilities and ways to realise possible futures rather than predicting exactly what will happen. In this *possibility perspective*, the existence of a plurality of futures is crucial and the keyword is, again, *scenario*.

Within this perspective, different kinds of futures have been introduced: *possible, plausible, probable* and *preferable*. The relationship between them is often represented with a 'futures cone' (Hancock & Bezold, 1994), elaborated by Voros (2003) (Figure 1).

According to Voros (2003), *possible futures* include all the futures we can imagine – also what might happen, even if unlikely. In the cone, possible futures correspond to the largest range. The *plausible futures* concern cases that could happen according to our current knowledge of how things work now. In the language of IPCC, which we introduced previously, this set refers conceptually to *projections:* they consist in that part of possible futures that stems from our current understanding of physical laws, sociological models, technological knowledge, and so on. The class of plausible futures contains a sub-class of cases that are supposed likely to happen as a continuance of current trends: these are named *probable futures*. Some probable futures correspond to what IPCC calls *predictions* or *forecast*: they are those probable cases that are considered more likely than others, and within this cone, the most likely is the 'business-as-usual' version which consists in a linear extension of the present.

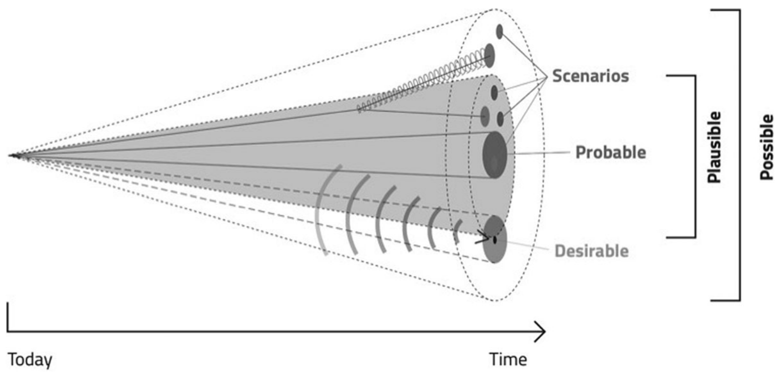



**Figure 1.** The futures cone of the Erasmus+ project I SEE 'Inclusive STEM Education to Enhancenthe capacity to aspire and to imagine future careers' (The I SEE project (https://iseeproject.eu) is co-funded by the Erasmus+ programme of the European Union. Grant Agreement n 2016-1-IT02-KA201-024373) (re-elaboration from the Voros' cone – Voros 2003).

While plausible and probable futures are largely concerned with informational or cognitive knowledge, *preferable* (also known as *desirable*) scenarios can depend, with high sensitivity, on contingencies or unexpected choices. Such contingencies and choice can concern what people want to happen; in other words, these futures are more emotional rather than cognitive and are thus more subjective than the other versions. In order to think in terms of preferable futures, people have to reflect on their current values and desires, their identities, their competences and their cultural points of view, and then imagine a preferred scenario in which they would like to live. To practice envisaging preferable futures is a way to develop what futurists call *foresight* or *anticipation*: the ability to build a vision by detaching from the current situation.

Futures scientists target their actions both at individuals and several types of groups, such as policy-makers, entrepreneurs, associations, educational institutions, including schools, teachers and students. Two interesting examples are the activities proposed by the non-profit association *Teach the future*, founded by Peter Bishop (http://www.teachthefuture.org), and the Italian project, *Anticipation*, led by Roberto Poli at the University of Trento (http://www.projectanticipation.org). Crucial concepts on which the educational activities are developed include the distinction between possible, plausible and preferable futures (Voros, 2003) and the concept of *foresight* or *anticipation* (Poli, 2010) that, unlike forecast (which goes from present to future), starts by imagining possible futures and, through *back-casting* activities, returns to the present in order to design possible actions that can foster the achievement of a desirable scenario.

The inclusion of futures within school curricula globally is rather a rarity and the topic is entirely absent from the Italian science curricula. One interesting exception is Australia, where FS have been an established aspect of curriculum and pedagogy since the 1960s. The topic was given high status by the Commission for the Future within the Bicentennial Futures Education Project (Slaughter, 1989). FS have also been an explicit item in curriculum documents in South Australia since 2002. This framework helped teachers to explore possible and preferred futures and to incorporate a futures perspective in science curricula (Paige & Lloyd, 2016).

In the light of all these remarks, the third – and last – set of principles includes: *(3.1) making the learning of science relevant from a personal perspective* (Stuckey et al., 2013). *This operationally implies the enrichment of science teaching with activities aimed at (3.2) developing personal engagement, creativity as well as foresight and anticipation attitude and (3.3) encouraging students to take agency for their future.*

## The module

The three sets of principles introduced in the previous section guided the design of a future-oriented teaching module (20 h), targeted towards secondary school students at grade 12 (17–18 years old). The scientific topic of the module is climate change, and activities aimed at developing transversal skills typical of LFA and GOPP for project planning are integrated with the scientific content. The two choices implied the involvement of professionals in these fields (Prof. RR, expert in climatology, and Dr MR, expert in project planning) in the activities of design and/or implementation.

The module included: (a) *two lab-sessions* designed to enhance students' knowledge on climate change and guide them to appropriate basic concepts of the science of complex systems, i.e. circular causality and feedback (according to the first set of principles); (b) *five sessions* designed to develop vocational skills related to LFA and GOPP (according to the second set of principles) and to engage the students personally in a creative and future-oriented activity (according to the third set of principles).

In the following section, the module is described in more detail in order to show concretely how the principles were implemented.

### *Climate change lab-sessions*

The two sessions were designed to enable students to:

(1) understand the greenhouse effect and the energy balance mechanism, i.e. how changes in the composition of the atmosphere cause changes to the Earth's surface temperature;
(2) grasp the concepts of circular causality and feedback and use them to analyse the complex issue of climate change;
(3) understand the role and specificity of modelling in the analysis of complex systems, such as the concept of scenario and the difference between prediction/projection;
(4) become familiar with the language of the IPCC (the Intergovernmental Panel on Climate Change) reports targeted at policy-makers.

The first lab-lesson is a general introduction concerning climate models and issues which are at the centre of the scientific controversies, like the anthropogenic causes of climate change and the scientific argumentations in favour of this position. The core scientific concepts of the lesson are absorbance and its fundamental role in interpreting the thermal effects of radiation. The relation between absorbance and temperature is then discussed regarding the temporal and causal structures it introduces, paying particular attention to the concept of feedback and circular causality. The epistemological distinction between linear and circular causality is highlighted, stressing that circular causality means that causes and effects cannot be clearly distinguished, and effects retroact on causes, strengthening (positive feedback) or softening them (negative feedback). Students are presented with some consequences of this relationship – such as melting glaciers, rising sea levels, changing eco-systems, migrations, increased frequency of extreme phenomena (such as river flooding, drought, heat waves) – and guided to recognise positive and negative feedback loops.

The lab-experiments, carried out by pairs of students following a list of open-ended questions and discussing the results together, concern empirical exploration of the physical laws and mechanisms characterising the radiation-matter interaction that is at the base of the greenhouse effect.

In the second session, the focus is placed on the IPCC report (2014) and lab-experiments regarding the greenhouse effect. In the lab-lesson, the expert (GT) points out some important concepts of the IPCC language (i.e. mitigation, adaptation, vulnerability, scenario concepts, difference between prediction and projection) and discusses data excerpts from the document about greenhouse gases emissions and future climate scenarios. Particularly, the introduction of the difference between prediction and projection allows evaluation of the different scenarios from a mitigation (act on the cause) and adaptation (act on the effect) perspective. In the lab-experiment, a simplified situation is reproduced in order to build a greenhouse model able to explain how and why a change in the make-up of the atmosphere could produce a change in the average of the Earth system temperature; pairs of students collect and plot data (using software) that are modelled using the previous concepts and laws and discussed in terms of feedback and energy balancing. The expert re-introduces the issue concerning the anthropogenic forcing of greenhouse: the relation between absorbance and temperature is hence re-interpreted as a bridge between the human causes (e.g. greenhouse gases emissions) and the physical mechanism of global warming (a change in the average temperature of the Earth's system).

As a final activity, a summary document on climate change is given to the students; we wrote this to clearly highlight the various dimensions involved in the problem and specific language of the IPCC report, together with the logical argumentations and causal links. The document is rather long (two and a half pages): as well as the problem of greenhouse gases emissions, it includes issues relating to dimensions like: political negotiations; urban, territory and social vulnerability; climate migrations; the lack of scientific literacy; insufficient citizenship engagement. Through this activity, we asked students to read this text, to underline the problems suggested by the text about the main issue of climate change, to recognise the structure and specific language of the IPCC report and to identify the various dimensions involved in the problem, both the scientific dimension and the adaptation and mitigation perspectives. Finally, we asked them to build a map in order to sketch up a hierarchy between the highlighted problems in terms of cause–effect relationships. The analysis of the document introduces elements that are used in the following activities.

The two lab-sessions on climate change are part of a path already tested by the research group during the past years (Venturelli, 2015; Tasquier, Pongiglione, & Levrini, 2014; Tasquier & Pongiglione, 2017; Tasquier, Levrini, & Dillon, 2016).

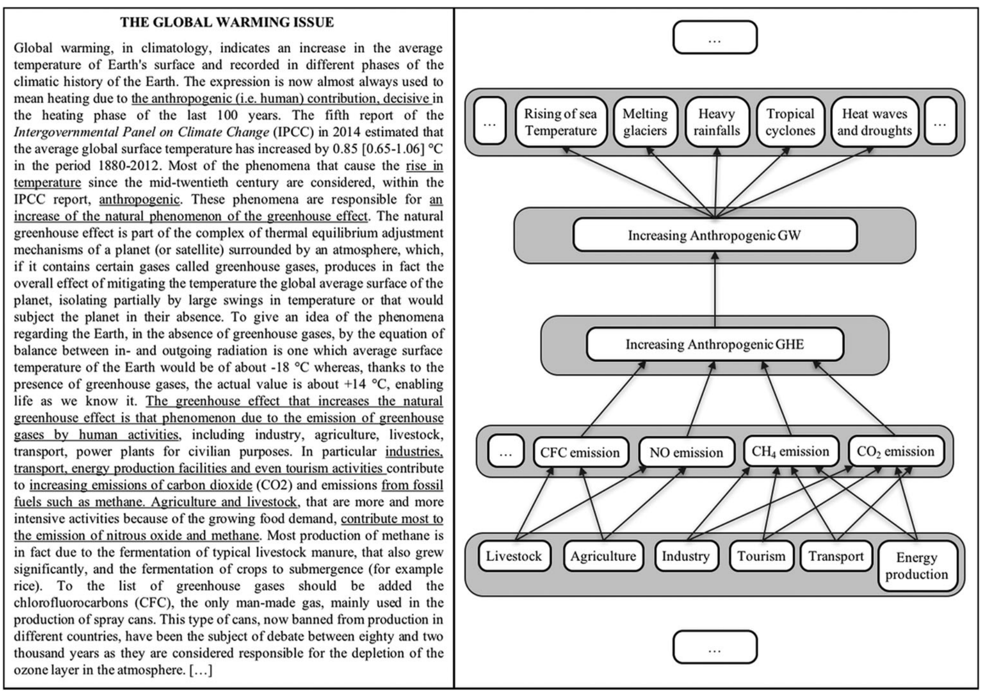
### Project planning sessions

The five sessions devoted to project planning have been designed in collaboration by the authors of the paper along with a Master's degree student (IV), the classroom teacher (PF), and an expert in European project planning (MR) (Venturelli, 2015; Tasquier, Branchetti, & Levrini, 2019; Tasquier, Levrini, Laherto, Palmgren, & Wilson, 2018).

Two sessions aim to develop skills for analysing the present situation, while three are dedicated to designing a project.

In the two 'present-focused' sessions, the students are introduced to GOPP and LFA. and taught how to analyse documents in order to build the *problem* and the *objective tree*. More specifically, we prepared different texts of increasing complexity, with the last being our synthesis of the IPCC report on climate change, already provided in the last session on climate change. Because of the length and complexity of the latter document, the map that the students are supposed to build is rather big (Figure 2). However, we left them to cope with the entire document and its many dimensions (e.g. scientific, technological, political, social, urbanistic, educational) themselves, so as to enable each student to find the type of problems that could resonate with their own intellectual, political, or emotional tastes. After construction of the problem tree, the module foresees that the students are guided in turning it into an objectives tree (Figure 3).

In the three 'future-oriented' sessions, students are engaged in real and concrete activities of project design. They are required to venture into the construction of a project in response to a call entitled 'Rimini [their city], the ideal future city in which to live'


THE GLOBAL WARMING ISSUE

Global warming, in climatology, indicates an increase in the average temperature of Earth's surface and recorded in different phases of the climatic history of the Earth. The expression is now almost always used to mean heating due to the anthropogenic (i.e. human) contribution, decisive in the heating phase of the last 100 years. The fifth report of the *Intergovernmental Panel on Climate Change* (IPCC) in 2014 estimated that the average global surface temperature has increased by 0.85 [0.65-1.06] °C in the period 1880-2012. Most of the phenomena that cause the rise in temperature since the mid-twentieth century are considered, within the IPCC report, anthropogenic. These phenomena are responsible for an increase of the natural phenomenon of the greenhouse effect. The natural greenhouse effect is part of the complex of thermal equilibrium adjustment mechanisms of a planet (or satellite) surrounded by an atmosphere, which, if it contains certain gases called greenhouse gases, produces in fact the overall effect of mitigating the temperature the global average surface of the planet, isolating partially by large swings in temperature or that would subject the planet in their absence. To give an idea of the phenomena regarding the Earth, in the absence of greenhouse gases, by the equation of balance between in- and outgoing radiation is one which average surface temperature of the Earth would be of about -18 °C whereas, thanks to the presence of greenhouse gases, the actual value is about +14 °C, enabling life as we know it. The greenhouse effect that increases the natural greenhouse effect is that phenomenon due to the emission of greenhouse gases by human activities, including industry, agriculture, livestock, transport, power plants for civilian purposes. In particular industries, transport, energy production facilities and even tourism activities contribute to increasing emissions of carbon dioxide (CO2) and emissions from fossil fuels such as methane. Agriculture and livestock, that are more and more intensive activities because of the growing food demand, contribute most to the emission of nitrous oxide and methane. Most production of methane is in fact due to the fermentation of typical livestock manure, that also grew significantly, and the fermentation of crops to submergence (for example rice). To the list of greenhouse gases should be added the chlorofluorocarbons (CFC), the only man-made gas, mainly used in the production of spray cans. This type of cans, now banned from production in different countries, have been the subject of debate between eighty and two thousand years as they are considered responsible for the depletion of the ozone layer in the atmosphere. […]



**Figure 2.** Example of problem tree.

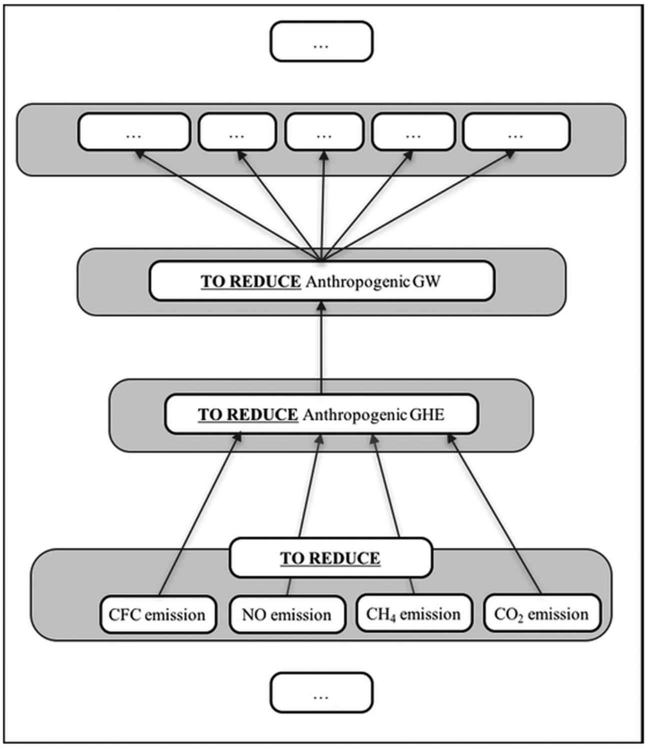



**Figure 3.** Example of objective tree.

(Annex 1a), by designing a project following a specific template (Annex 1b). In the call, a list of general objectives is given, from which the students have to choose their own priorities. The objectives refer to various parts of the document previously analysed. Hence, the choice of few general objectives enables them to zoom in on that part of the goal map where they wish to act. The project template, designed to simulate a European model in a simpler form, is organised in terms of: title, objectives, concept, team-work, activities, stakeholders, Gantt chart and impact (Annex 1b).

In order to encourage the students to take *agency* of their future, develop *foresight/anticipation and back-casting* attitude, enhance *creativity*, and feel *personally engaged* (our third set of design principles), the activities require them to: choose a part of the goal map where they wish to act (*agency*); think about a desirable scenario and an ambitious goal they hope to reach (*foresight/anticipation*); look for a creative idea that could characterise the project (*creativity*); build a working team by imagining possible professional roles for themselves in the project (these could include for example entrepreneurs, lifeguards, architects, policy-makers, researchers, teachers, members of civic associations) (*personal engagement and identity formation as future professionals*); and articulate the project idea into a structure of specific objectives, strategies and time graph *(agency through back-casting).*

During the last session, the students are requested to present their projects for the evaluation process to a committee of experts (composed of MR and other members of the research team), who are responsible for providing feedback on the work.

## The implementation context, data sources and methods of data analysis

As already mentioned, the module was implemented in a grade 12 class of the Scientific Lyceum A. Einstein in Rimini. The activities followed up the thermodynamics unit and consisted of 7 extra-curricular sessions. The activities were designed solely for volunteer students of the class; 24 out of 25 students (15 females and 9 males) participated in the project.

The first two lab-sessions were led by GT. The five project planning sessions were led by MR with the support of OL. GT and the Master's student, IV, were tutors. The classroom teacher supervised the activities and helped the team interpret the classroom dynamics. For the activities, the students were divided into 5 operative groups. At the suggestion of the class teacher, the groups were formed by the students themselves.

The implementation was mainly monitored and analysed to give a contribution to the first question challenging science education researchers that we posed in the beginning, focusing, in particular, on the research question: *Did the module impact students' ways of thinking of the future? If so, how?*

In order to answer this question, several forms of data were collected: (a) a pre-test about the perception of the future, consisting of a written essay where students were required to 'Imagine yourself on a spring day in 2030 and imagine how the phenomenon of global warming will have changed the environment around you and the place where you think you will be living'; (b) audio and video recordings of all the sessions and the groups' work; (c) the students' projects; (d) notes by researchers; (e) 12 individual semi-structured interviews,[3] carried out at the end of the module (Table 1). The sample was set up to represent the variety of the entire group according to: (a) gender, (b) level of performance (both generally and for physics), (c) level of involvement within the project and level of satisfaction. Thanks to this stratification, the interview data could be considered significant and reliable in representing the different features of the class that we considered relevant for the scope of the study. Participation in the interview was on a voluntary basis but all twelve students invited for the interviews agreed to be part of the survey.

The written essays and interviews were the richest and most versatile data, and we used them to answer the first research question. We could consider these two sources comparable since the interview protocol included a section that highlighted the same points as the written essays and required the students also to rethink and meta-reflect on what they wrote at the beginning. Furthermore, the interview protocol included sections where students were asked to comment on the whole module. The interviews allowed us not only to comprehend students' attitudes towards the future but also to understand the impact of different parts of the module on their future perception.

**Table 1.** Data collection.

| Main data sources | Moment of submission | | |
|---|---|---|---|
| | B | D | E |
| Written essay (about future in 2030) | X | X | |
| Audio and video recordings of the sessions | | X | |
| Researchers notes | | X | |
| Individual semi-structured interviews | | | X |

Note: B: beginning of the path; D: during the path; E: at the end of the path.

Given the sample and the research issues, we opted for a semi-qualitative methodology of data analysis (Anfara, Brown, & Mangione, 2002) inspired by Grounded Theory (Glaser & Strauss, 1967). The analysis has been performed as the first stage of an iterative process aimed to develop theoretical constructs or, at best, local theories. More specifically, the main goal of the data analysis we carried out in this pilot study was to search for a *sensitizing concept* (Glaser & Strauss, 1967), able to capture and describe the effect of the module implementation, guiding further rounds of increasingly structured implementations focused on developing a humble theory.

The graphs we will report do not have any statistical meaning: they serve as tools to outline what happened in this specific context. Nevertheless, these results are compared with a Eurobarometer report to check if our investigation shows patterns already revealed by large-scale surveys. The Eurobarometer report we considered is entitled Public Opinion on Future Innovations, Science and Technology, Aggregate Report, Eurobarometer Qualitative Study (2015). It presents a survey on the public response to some scientific and technological innovations that could be part of the daily lives of European citizens in fifteen years, i.e. in 2030, in four different areas: home and lifestyle; health; communication and relations; environment. The report illustrates the general perceptions of scientific and technological innovations and spontaneous projections regarding tomorrow's society. The study is based on 96 semi-structured discussions ('focus groups') conducted with small groups of citizens (age range 18–64 years old) in 16 EU Member States. The main part of the discussion is dedicated to reactions and discussions of the participants regarding possible scenarios shaping the future. Disaggregated analyses to point out inconsistencies across age groups, education levels, and different Member States have been carried out. The main result is that 'in overall terms, people expressed similar hopes and concerns for the future in terms of what science and technology will bring – however the extent to which these views affected their overall view did differ' (Eurobarometer, 2015, p. 7).

Because of the theme and the authoritativeness of the report, we used the results of the Eurobarometer survey to triangulate those emerging from our analysis.

The data have been analysed with two main aims: (a) to compare the views of the future as provided by students at the beginning and at the end of the implementation; (b) to search, in the data, for *key-ideas* to start up a process aimed at revealing students' perception of change due to the approach.

The data were analysed through an iterative process that foresaw both bottom-up debriefing phases, designed to identify the emergent aspects in the data and generate interpretative ideas, as well as top-down phases, aimed at validating interpretative hypotheses formulated by the group of analysts. In order to reach an acceptable level of internal validity, the top-down analysis was conducted through a triangulation process between several researchers in physics education. The triangulation process was carried out by articulating the work in individual analysis phases, followed by phases of collective discussion among researchers. This iterative process of multiple triangulations led to a gradual refinement of the categories identified in the analysis.

Both the teacher and the expert in PCM (who were present in the class during the sessions but were not part of the research process) were required to read, check and give feedback on the quality of the analysis and the results (inquiry audit).

## Data analysis and results

The initial picture of the students' view of the future was drawn from the written essays. In the first bottom-up phase of the analysis, three researchers (GT, IV, OL) carried out an independent reading of students' writings before pointing out three main focal points: the difficulties of several students in imagining a future scenario; the multiplicity of dimensions in which changes are perceived; the variety of attitudes toward the future. The researchers, then, systematically analysed the data to figure out the initial state, answering the following three sub-questions: (a) how many students are able to imagine a future scenario which is different from the current one? (b) what are the main dimensions of change (e.g. technological, environmental) they perceive? (c) what attitude do students display toward the future (e.g. positive, negative, neutral)?

The analysis led us to identify the students who did not perceive any change, and categories to code the dimensions of change and attitude. The final categories and results are reported in Figure 4(a,b). In Table 2, examples of students' answers for each dimension of change are reported.

The graphs show that almost one third of the students do not expect any change in the coming years (Figure 4(a)), whilst the others perceive change in three main dimensions: environmental, societal and technological (Figure 4(b)).

The relationship with the technological future appears ambivalent and diversified: some students imagine a return to a less technological world, others imagine a widespread expansion of existing technologies, others predict science fiction scenarios (like underwater cities). Only a few try to think about real innovations. Very few of them describe the future as a stimulating challenge that could allow humans to explore new social and political structures and to develop new technologies (Figure 5).

The analysis shows that young people feel, on one hand, the fascination for a constantly evolving world and, on the other, they see technology as the cause of several threats, like the replacement of human beings in contexts of social interaction and the labour market.

This result resonates with the Eurobarometer report, where a similarly ambivalent and diversified attitude is observed also among the younger members of the sample group.

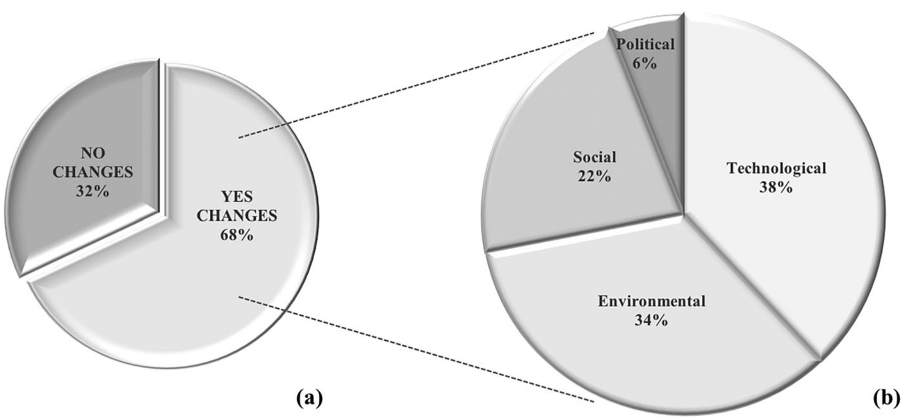



**Figure 4.** (a) Percentage of students who see changes or not in the future; (b) Sectorial breakdown of the changes.

**Table 2.** Illustrative quote about the dimensions of change.

| **Environmental** |
|---|
| 'The increase in the earth's temperature has caused a further melting of the glaciers and [because of] the raising of the water level, the man is trying to adapt to live below sea level and below the rivers.' (F14) |
| **Social** |
| 'Unfortunately, the relationships between us have changed, we tend to feel more and more by mobile phone and to hide behind a screen.' (F18) |
| **Political** |
| 'Fifteen years ago, all this seemed unthinkable, like science fiction stuff because of the indifference of international politics that filled the mind of public opinion with false proclamations and ineffective pacts. Now […] climate change sceptics have now changed their minds, as has the international community, which has finally imposed strict limits on greenhouse gas emissions unanimously, especially to eastern industries.' (M7) |
| **Technological** |
| • *Science Fiction:* 'Even if it is a big problem, the solution to the rising sea level will be found. In case entire cities will be submerged and we find ourselves underwater, professionals like architects and engineers will have already thought of a solution: floating cities zero emissions, self-sufficient thanks to energy solar and wind power.' (F16)<br>• *Innovative tech:* 'Houses will be covered with hydrophilic material to remedy extreme weather events, and [there will be] great innovations for transport [like] expensive but efficient low-level flying vehicles.' (F1)<br>• *Low tech:* 'An aspect that I greatly appreciate is the scarce use of electronic objects: due to the intensification of the number and frequency of extreme weather events, it has become difficult to maintain stable lines of communication.' (F4)<br>• *Diffusion of existing tech:* 'The photovoltaic systems will have vastly spread among the population and most of the buildings will have an energetic system based on renewable energies.' (M6) |

There, the positive impacts are generally related to: efficiency, ease, freedom, comfort, speed, simplicity, modernisation, convenience, improved quality of life and a more environmentally friendly existence. The negative impacts are generally related to: loss of socialisation skills/dehumanisation, data security concerns, unemployment/job losses due to the automation of work, loss of privacy/freedom, social exclusion, pressure to keep up with changes, laziness and 'de-skilling' as one forgets how to do certain tasks.

The main difference from our results is that none of our students seem to worry about violation of privacy, a problem instead keenly stressed by participants in the

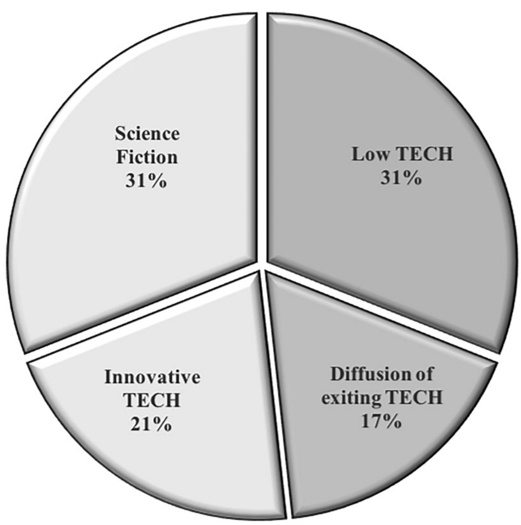



**Figure 5.** Students' relationship with technology.

Eurobarometer survey. However, although the main results were very similar across the age range, the latter survey was able to highlight that

> older people tended to be more concerned about the implications of these advances on data security. Younger people who have grown up in the digital age were just as likely to mention these concerns (more aware perhaps of the implications for data security) but tended to be less concerned about this in general than older people: they were instead more worried about specific (mis)usage of this data. (Eurobarometer, 2015, p. 8)

This result of the Eurobarometer represents a possible explanation of the difference we noticed.

Regarding students' attitudes toward the future, most of them feel a sense of detachment, fear and anguish. Some students demand influential action from other people (scientists, innovators, policy-makers); other students show a similar sense of devolution but nuanced as confidence in science and technology. Only a few of them feel optimistic about the adaptability of humans and are curious about the cultural or technological challenges that the future offers (Figure 6). In Table 3, examples of students' sentences for each category are reported.

To sum up, the initial picture confirms the trends observed in the Eurobarometer report and shows a widespread feeling of scepticism as well as a tendency to deny the problem and remove the future from their personal horizon.

We constructed the final picture of students' relationship with changes and the future by analysing the post-module interviews, which included questions related to the initial essays. What emerges is, in most cases, a significantly different relationship. More relevantly, it emerges that the students felt they had developed some skills for building fruitful and structured pictures of the present, characterised by internal relationships between different stakeholders and problems, and able to make them feel actively participant in

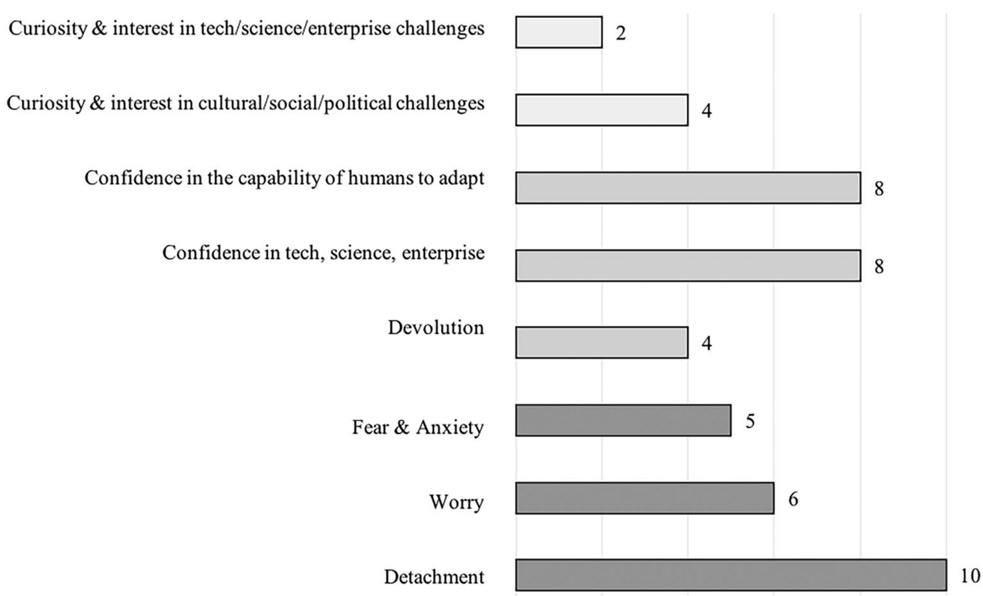



**Figure 6.** Students' attitude toward the future.

**Table 3.** Illustrative quote about students' attitudes toward the future.

| | |
|---|---|
| **Curiosity and interest in tech/science/ enterprise challenges** | 'It is exciting to think that we will address big problems thanks to technological innovations, like creating new ways to make water potable or to produce alternative food.' (F15) |
| **Curiosity and interest in cultural/social/ political challenges** | 'I want to believe that the problems to be fought will be addressed with the awareness of being in 2030 and with the desire to progress, learning from the past. We will live in a cosmopolitan world without cultural barriers.' (F4) |
| **Confidence in the capability of humans to adapt** | 'In 2030 the life quality will improve, and man will learn how to adapt to nature, he cannot just command it' (F14) |
| **Confidence in tech, science, enterprise** | 'Science will give its contribution with new analyses and discoveries.' (M6) |
| **Devolution** | 'Someone else will find the solution to the problem, even if large […] For example, if entire cities were submerged, the architect would have already thought of a solution.' (F16) |
| **Fear and anxiety** | 'The situation [is] increasingly in decline and considering the crisis in which are immersed, I don't think our dreams will ever come true.' (F10) |
| **Worry** | 'I am concerned that the insecurities and unpredictability of the climate can trigger psychological problems in people.' (M7) |
| **Detachment** | 'I don't see the problem of future's change because I am just a drop in a huge sea and cannot influence the future … everything is so complicated.' |

current social and environmental problems. While their perception of the future was changing, it was also changing the perception of their role in the present.

To unfold these main general results and search for indicators of the impact of the activities, we carried out the second phase of the analysis, articulated on two levels. On one hand, we searched through students' interviews for recurrent terms they used to comment on the module or to describe their view of the future. The aim was to flesh out general trends, from the students' words. On the other hand, we focused on a few students to search for inspiration and ideas to clearly grasp what happened during the activities. Specifically, we searched for those students who were able to express in clear and articulate ways which activities impacted their perception, and how. The combination of the two levels of analysis allowed us to identify what we consider the main result of the study: a sensitising concept that seems to hold the potential to become a theoretical construct which is able to describe and interpret the impact of our approach.

The main result of the interview analysis is that all the students but one used similar terms to express how the activities impacted their knowledge: the activities are said to have contributed to 'widening their perspectives' and 'making the future become closer'. Widening, in students' words, could refer to: (1) the *knowledge of the topic they believed to have acquired* (of climate change and related aspects like migration, increased vulnerability); (2) the range of *possible actions*; (3) the range of *new ways of thinking* and looking at problems, mainly informed by the PCM tools and concepts of the science of complex systems (e.g. complex patterns of causality); and (4) the *awareness* and confidence in their own potential and role as agents.

Regarding the future, it was perceived as 'closer' in several senses: (1) closer *in time*, in the sense that the year 2030, from being far and unimaginable became conceivable as a set of possibilities; (2) closer *to reality*, in the sense that it became approachable through concrete actions in the present; (3) closer *to themselves*, in the sense that the future moved within their reach and they found ways to see themselves as agents of their own future.

In order to show that 'widening and approaching' are not student-specific results but emergent trends, we report in Figure 7 the frequency of these aspects in students' interviews. All the students but one showed at least three markers of widening or approaching.

In order to search for indications to reveal what happened during the activities, we focused on students who provided articulated answers. Here we report and comment on statements by two students: Elena and Sara. Their initial graph positions show that they both imagine a world similar to the present or with a low technology/same technology as now. They desire a return to an imaginary peace of the past since one of them (Elena) feels worried and the other (Sara) feels detached from what will happen in the future.

The first comment is from Elena:

> The project has helped us to think, to do something in relation to something else […] what I learned about shifting from problems to goals impressed me a lot, it also 'woke me up', in the sense that often we perhaps see all the problems and do not see even one positive aspect, but with this project we have seen that things are feasible and they depend on how we act, we didn't just talk about abstract things. […] If we are too focused on one thing, we cannot see it in a global context … instead we must always have a vision which is both global and transversal, and then of course, when necessary, we must be able to explore details, but always remember the surrounding context. (Elena)

In this comment, four main aspects are worth stressing:

(1) Elena became able to build up a comprehensive image of the many problems in the present related to climate change, where the various aspects are related to each other, 'something is in relation to something else': the present is not yet perceived only in terms of 'dust of moving splinters' but as a system in which the components are connected to the others by means of mutual relationships. We believe that Elena was encouraged to develop this kind of scaffolding skills during the PCM activity on problems-tree and through the analysis of notions typical of complex systems (self-organisation; mutual relationship between agents and system). Indeed, all these activities aimed to provide a more structured perception of the present and the feeling that such ways to analyse a problem could be applied in other situations.

(2) Elena confirms that the young tend to perceive the future as overwhelming and bleak 'often we perhaps see all the problems and we do not see even one positive thing', but thanks to the activities on the problem-tree and the objective-tree (*what I learned*

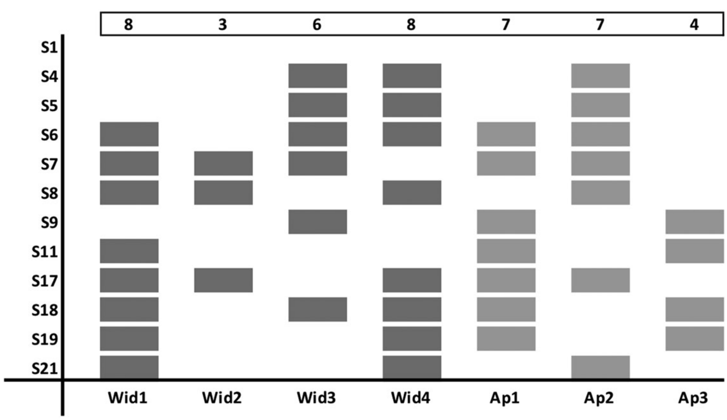



**Figure 7.** Number of students who express the sense of 'widening their perspectives' and perceive the 'future closer'.

*about shifting from problems to goals impressed me a lot)*, she did not yet feel stuck because of this feeling. On the contrary, these activities 'woke her up' and she saw possibilities and assumed a *planning* attitude instead of surrendering in the face of a number of problems. Elena discovered herself to be a possible agent of her future, because she discovered that many actions are feasible and within her reach: 'with this project we have seen that things are feasible and they depend on how we act'. She thus moved toward a conception of the relationship between future and the present and began to think in terms of possible scenarios that depend on present actions.

(3) For Elena, the key to change was to have a 'global and transversal vision', a big picture from which to zoom in on concrete local actions, without getting lost: 'we must always have a vision which is both global and transversal, and then of course, when necessary, we must be able to explore details, but always remember the surrounding context.' We believe that this type of attitude was encouraged when we encouraged the students to adopt, during the PCM activities, a systemic perspective, while focusing on single independent agents, and to consider also big feedback loops that oblige them to re-think local actions in terms of global dynamics.

Another very significant comment comes from Sara:

> [the activities] have opened my mind and provided many more points of view than I had before. At the beginning, though, [the activities] really demoralized me because I thought I was not able to do it. I thought I did not have a mind that could look forward and see more than I could see before. Instead, through the project, I was really able to reach a point I previously did not believe my mind could arrive. […] The project changed my way of thinking, not only for me but also for the others. (Sara)

Also in this comment, several aspects are worth stressing:

(1) Sara mentions an initial sense of frustration 'At the beginning, the activities really demoralized me because I thought, I was not able to do it', but she recognises that the activities 'opened my [her] mind' and, mainly, 'opened many points of view', a set of possibilities to look forward to. She feels she had developed new skills and that something changed (at the beginning, she did not feel able to find a project idea). She started to adopt a way of thinking in terms of possibilities and this allowed her to overcome the feeling of frustration: this way of thinking, then, acted for her as a scaffolding factor. Also, she discovered potential skills that she did not believe she had: 'through the project, I was really able to reach a point I previously did not believe my mind could arrive'.
(2) For Sara, the key moment was the activity on project design, which obliged her to tackle a real challenge and, by providing her with the necessary support for success, enhanced her self-confidence and 'changed' her 'way of thinking';
(3) Sara was also able to note changes in her classmates: 'The project changed my way of thinking, not only for me but also for the others'.

The two cases of Elena and Sara are not representative of all the students. However, they represent a rich source of insightful ideas inasmuch as, in their words, it is possible to recognise the potential of the approach for developing very important skills. We will discuss this result in the next section.

## Discussion

The analysis of the final interviews revealed some global trends: the approach seems to be effective in impacting on students' future perception in terms of 'widening and approaching'.

On the other hand, the analysis of the cases of Elena and Sara highlighted that the approach appeared promising for the development of specific skills to structure ways of thinking about the present, the futures, and their back and forth-relations. Furthermore, the analysis of the two cases allowed us to identify which activities seemed to be effective in developing those skills. Specifically, the activity designed to build the problem tree appeared particularly effective in guiding students to point out and map causal relations among the problems. The development of these skills seemed to have impressively changed the students' relationship with the present: although problematic, it became comprehensible and 'cognitively manageable'. The subsequent activity, aimed at turning problems into objectives, impacted deeply at an emotional level: students gained a concrete, operational skill to turn problems into possible goals. Again, the activities aimed to design the final project pushed the students to develop skills to: move globally locally, from general objectives to specific actions; grapple with the difficulties of anticipating possible futures and use creativity to imagine desirable futures; play a role in a team and consider possible future careers; design actions and develop a sense of agency regarding possible futures.

The emergence of this bunch of skills is the main result of the study. They are, in our opinion, so valuable that they deserve a name. We call them *future-scaffolding skills* since they refer to the capability of organising knowledge in the present, imagining futures and moving dynamically and consciously, back and forth, globally locally, between different time dimensions. Thanks to their emergence, this pilot study led to the identification of a *sensitising concept*, i.e. a concept that has the potential to theoretically orient further studies and can be progressively tested, developed and refined as a theoretical construct (Glaser & Strauss, 1967). This is what we are developing through further rounds of design and implementation (Tasquier et al., 2019). and this is an aspect that highlights, a-posteriori, a further difference of our approach with respect to SSI. Future-scaffolding skills are not in the current agenda of the SSI approach, but they can represent a significant extension or elaboration of that approach.

To go back to the theoretical foundations of the study, the analysis shows that students developed these *future-scaffolding skills,* since their ways of reasoning about present and future resulted to be enriched with: (i) the logic of *causality* (recognise cause–effect relationship and build causal maps; distinguish between linear and circular causality, recognise feedback loops); (ii) the logic of *uncertainty* (the difference between projection and prediction); (iii) the logic of *possibilities* (the difference between plausible, probable and possible scenarios); (iv) the logic of *multidimensional, multi-perspective and values-based problems analysis* (how to formulate a complex problem concerning the future; who is involved in decisions and who are the stakeholders); (v) the logic of *action* (how we can concretely contribute to fostering a desirable future). Students discovered an opportunity to enrich their thinking with the logic of causality, uncertainty and possibilities, thanks to the sessions designed to implement the first set of principles, where scientific contents were reconstructed so as to flesh out the causal models, and where concepts of the science of complex systems were discussed. These aspects were then strengthened during the 'present-focused sessions' of project planning, where the construction of the problem tree and its transformation into an objective tree represented the core activity that bridged content-based sessions with the future-oriented part of the module. This part was fundamental in exposing students to the logic of *multidimensional, multi-perspective and values-based problems analysis* and to the logic of *action*.

Significant open issues have been identified by this pilot study:

(a) how can analysis of the impact on students of the approach be refined? What data do we need to collect in further implementations?
(b) how can the approach be extended to the design of further topics?
(c) how can the approach be, eventually, integrated into regular teaching?

These issues are at the base of the Erasmus + Project 'I SEE – Inclusive STEM education to Enhance the capacity to aspire and to imagine future careers' (https://iseeproject.eu). This project, launched in September 2016, was inspired by the positive results of the paper presented here. The partnership consists of three secondary schools (Italy, Finland, Iceland), two universities (Italy, Finland), an environmental NGO (*Landvernd*, Iceland), a teachers' association (*ASE*, United Kingdom) and a private foundation (*Fondazione Golinelli*, Italy).

The I SEE project aims to design innovative approaches and teaching modules to foster students' capacities to imagine the future and aspire to STEM careers. The I SEE modules are expected to develop future-scaffolding skills – in and out of school – through STEM education, by dealing with multi-disciplinary and future-oriented relevant topics such as climate change, artificial intelligence, quantum computing, and nanotechnologies.

In addition to the creation of these specific I SEE modules, the outputs of the project include a guide for developing further I SEE modules after the project ends, case studies, and recommendations to policy-makers for an inclusive STEM education. The analysis of the follow-up of this study and the first I SEE implementation are leading us to refine and operationalise the markers of widening and approaching, as well as identify two kinds of future-scaffolding skills and their relationship with the markers (Tasquier et al., 2019). Independently of the I SEE project, we believe that this approach could be adopted in school contexts where project-based instruction is implemented.

## Conclusions

In the paper we presented the approach we have been developing to answer the question 'Can physics teaching contribute to developing skills for managing (rationally and emotionally) uncertainty towards the future and for projecting imagination forwards? If so, how?'

The question is demanding but, we argued, can be the driver of important aspects of innovation in science and, more in general, STEM education. Indeed, we saw that the topic of future offers the opportunity to embrace unusual aspects of science which are not always highlighted in teaching, such as its causal models and ways of dealing with uncertainties. In particular, we argue that the science of complex systems was particularly well-positioned to address this issue since, through its main disciplinary concepts and their epistemological status, it could provide a new vocabulary for reasoning about the future in terms of a plurality of possible scenarios. Then, we saw that the future offers an opportunity for transforming STEM education into a more global education of the young: it allows teaching to touch emotional (personal), societal and vocational dimensions. Personal, societal and vocational are precisely the three dimensions of relevance that, according to Stuckey, STEM education often fails to encompass (Stuckey et al., 2013). Furthermore, we saw that the topic of future can aid the development of creativity and encourage students to enhance their imagination. Above all, we saw that teenagers turned their learning of science into an opportunity to address their anxiety regarding global and future uncertainties.

We wind up this paper with the term 'to futurise' and with the claim that *to futurize STEM education is an interesting challenge that is worth addressing* (Branchetti, 2018). The term is the counterpart of the notion of 'de-futurising', introduced by Bergmann (1992) to describe a special feature of political discourses about the future. Policy scientists, Bergmann argues, aim to increase security and, to pursue this goal, their discourse tends to 'close' the future by removing any reference to its intrinsic uncertainty. On the contrary, argues Bell (2003), the researchers, like those involved in Futures Studies, should aim to teach people that the future is an open horizon, a dimension of freedom that can be creatively explored through the development of suited skills and desires. Searching for visions of the future is fundamental in order to support possible ways of acting creatively and consciously in the present with one's eye on the horizon. In the wake of Futures Studies, we also believe that STEM education should explore the possibility of explicitly 'futurising' its approach to contents and teaching methods, making students deal with uncertainties, possibilities and dreams as resources. Future-oriented STEM education should ideally become a new trend, which is now just in its early stages.

## Notes

1. We prefer the expression *transversal* skills rather than *soft* skills to stress the fact that such skills are not specific to a single disciplinary domain.
2. PCM, GOPP and LFA are not teaching strategies but professional techniques. They are not used here to promote science learning, but they are at the basis of activities explicitly aimed to develop skills of project planning. For these reasons, they should not be confused with the educational strategies that refer to project-based instruction where the activity of project-design is supposed to foster the development of conceptual and curricular knowledge.
3. In order to maintain anonymity, students were identified by pseudonyms, but gender distinction was maintained.

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## Annex 1

### *(A) Call: Rimini, the ideal future city in which to live*

As claimed in the IPCC report, two types of actions are required in order to address problems related to climate change: (i) action in the form of *mitigation*, i.e. action aimed at developing research and technological innovation to reduce the emission of greenhouse gases, as well as actions to convince all actors who are responsible for these emissions to reduce them; (ii) action in terms of *adaptation*, i.e. actions aimed to decrease, if not the hazard of the events, social vulnerability, as well as the exposure and vulnerability of the regions.

As far as adaptation actions is concerned, they can be of different types: structural (e.g. measures to protect the environment and securing the sites as well as measures to ensure an adequate urban planning); social, (e.g. measures to reduce the poverty or marginalisation of some social groups so as to reduce their social vulnerability); cultural (e.g. education, dissemination and capacity building actions aimed at changing the attitude of individuals and the community toward the complex phenomenon of climate change and its environmental, economic, political and social implications).

Team-work is required to build a **3-year** project where multi-dimensional actions of mitigation and/or adaptation have to be planned in order to transform Rimini into an ideal future city in which to live.

The project must contribute to achieving at least two general objectives from among the following:

(1) Imagining innovative forms of urban planning (***smart cities***) with the help of ICT tools (***information and communication technology***) in order to ensure sustainable development and a better quality of life (housing security, transport, green areas, *etc.*);
(2) Promoting active citizenship actions (***public engagement***) on climate change issue in areas at high risk both of social and economic marginalisation and of social vulnerability;
(3) Influencing ***policy makers*** to promote policies that encourage **mitigation and/or adaptation actions** in the economic-productive, scientific and social realms;
(4) Promoting information, communication and/or education strategies aimed at encouraging a cultural change related to climate change and the diffusion of **scientific citizenship competences**;
(5) **Reducing the emissions** produced by one or more of the major players in the business world (industry, agriculture, energy, tourism, fishing …) by influencing their behaviour.

## *(B) Template*

**(1) Title** (an acronym may also be used)
**(2) Objectives** (1 page)

Choose at least 2 general objectives of the call to which the project aims to contribute.

Identify the specific objectives that the project intends to achieve in order to pursue the general objectives.

**(3) Concept** (1/2 pages)

Describe the central idea that characterises the project.

**(4) Team**

Describe the composition of the participants using the table below.

**Table A1.** The team.

| Member of the group (name) | Skills and type of expertise (e.g. computer engineer, policy maker, member of an environmental association, *etc.*) | Affiliation Entities (e.g. City Hall, University, Association, Enterprise, *etc.*) |
|---|---|---|
| | | |

**(5) Set of activities and different target groups**

For each specific objective, describe the activities that your team is planning and the target groups, using the table below.

**Table A2.** Set of activities and target group.

| What (specific objective) | How (Activity) | To Whom (Target Group) | Who, among the team, leads the activity and who participate |
|---|---|---|---|
| S.O 1 | A 1.1 | | |
| | A 1.2 | | |
| | … | | |
| | A 1.n | | |
| S.O. 2 | A 2.1 | | |
| | A 2.2 | | |
| | … | | |
| | A 2.n | | |
| … | | | |
| S.O. n | A n.1 | | |
| | A n.2 | | |
| | … | | |
| | A n.m | | |

**(6) Stakeholders** (1/2 pages)

Identify the actors (different from the target groups), which must be involved in the project to maximise the probability of success and describe the type of involvement (why and how you plan to involve them).

**(7) Gantt Chart**

Illustrate the temporal organisation of the activities by using the following GANTT CHART.