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Recognition and operationalization of *Future-Scaffolding Skills*: Results from an empirical study of a teaching–learning module on climate change and futures thinking

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Abstract
This article takes its point of departure from the younger generation's problematic relationship with time and the future. A general sense of changeability and directionlessness in society compromises young people's confidence in themselves to make a difference as individuals in important global issues affecting their futures, such as climate change. Given recent aims and commitments of science education to promote sustainable development and student agency, this study explores how science teaching can help students imagine and face possible future scenarios and develop agency in the present to influence them. This article presents a science education approach to equip secondary school students with skills of futures thinking and agency that we call 'future-scaffolding skills.' It also shows the process for building an operational definition for recognizing those skills in students' discourse and actions. For this purpose, an empirical study was carried out in the context of a teaching-learning module on climate change, consisting of activities inspired by the field of futures studies. Essays, individual and group interviews, questionnaires, and video recordings of students' final projects were collected from 24 students (16-19 years old) from three European countries. The results contribute to operationally defining 'future-scaffolding skills,' consisting of 'structural skills' (the ability to recognize temporal, logical and causal relationships and build systemic views) and 'dynamical skills' (the ability to navigate scenarios, relating local details to global views, past to present and future, and individual to collective actions).

Keywords
climate change education, futures studies, future-scaffolding skills, science teaching

1 Introduction
This article takes as a point of departure concerns that have been raised about young people experiencing an alarming loss of hope that leads them to live in the present as if it were the only dimension that matters (Benasayag & Schmit, 2006; Giddens, 1991; Leccardi, 2009; Rosa, 2013). Sociologist Hartmut Rosa (2013) argues that accelerated social change has led to disorientation in society. Decisions and actions become directionless if they are not grounded in any image of the past, nor aimed at any stable future horizon. Rosa considers such a perspectiveless state as the endpoint of

social acceleration and calls it *frenetic standstill*, adopting a prior translation of the French term *inertie polar* by Virilio (1999). Frenetic standstill is a condition where events remain episodic in both individual and collective experience, so that "nothing remains the same but nothing essentially changes" (Rosa, 2013, p. 314). Other sociologists and philosophers have expressed similar views, like Leccardi portraying the present as "the dust of moving splinters" (Leccardi, 2009, p. 35).

As a result, young people, unlike past generations, tend to feel that the future is no longer a promise but a threat (Benasayag & Schmit, 2006), and struggle to imagine possible positive future scenarios for society. Empirical confirmation of these concerns has, to an extent, been found in surveys on people's perception of time and future. A Eurobarometer survey (Eurobarometer, 2015) shows limitations in young people's imagination and abilities to project themselves into the future. Several youth studies have analyzed students' writings on future and shown simultaneous pessimistic and optimistic views of the future (e.g. Cuzzocrea & Mandich, 2016; Heggli et al., 2013; Heikkilä et al., 2017). One finding is a duality in future thinking: the young may see their personal futures as positive and in their own hands, but the collective and especially the global future as hopeless, frightening and completely out of their influence (Cook, 2016; Heikkilä et al., 2017). This resembles the "two-track thinking" observed among adults (Leahy et al., 2010) as well as the young (Threadgold, 2012) in the context of the climate crisis, in which the global long-term future is conceptualized separately from one's own personal future. Norgaard (2011) explains this tendency as a strategy to cope with the fears and anxiety associated with the long-term future. In the field of environmental education, climate crisis denial and disavowal have been interpreted as psychological defenses against widespread eco-anxiety (Ojala, 2012; Pihkala, 2017). Such fears, according to Cook's (2016) study on young adults, appear to extend to "a loss of faith in the notion that humanity is progressing towards a positive future" (Cook, 2016, p. 528).

Such a problematic perception of time fundamentally impacts students' personal lives, as well as the societal and global issues humanity is facing. In particular, the climate crisis necessitates action guided by a sense of realistic hope and an active orientation toward the future (Ojala, 2012; Pihkala, 2017). Recently we have seen how the Fridays for Future youth movement initiated by Greta Thunberg has been able to activate the issue of the future for the younger generation. Maintaining and expanding such an active engagement with the future presents a major challenge for many societal stakeholders, including policymakers, the media, researchers and practitioners in business, psychology and social sciences – and educators.

Also the current global pandemic due to the novel coronavirus has deeply impacted the young generation's perception of the global challenges we are facing (Levrini et al., 2020). Issues have been raised about the role of scientists in society, and the contradictions, debates, and number of stakeholders who must collaborate to deal with such a global crisis. It has emerged in a clear and dramatic way how the many dimensions (economic, social, technological, educational) are connected to each other and that a choice at one level can influence all the other aspects. The pandemic requires people from all countries to think together about the future of the world, and make necessary systemic choices. Furthermore, due to climate change and environmental conditions, we can reasonably hypothesize that this kind of emergency will not be the only global and systemic crisis the world will face in the coming years. More and more, the young need to develop thinking skills to manage such complexity and, since they will be affected by what happens at a global scale in their everyday lives, feel they can have influence. It is becoming more and more important that they feel they can face global challenges as responsible and active citizens, and think about their futures and the future of the world as interconnected.

This article is framed within the general goals and commitments of science education to sustainable development and, within this framework, it sets out to explore how science teaching can respond to young people's experience of directionlessness and *frenetic standstill*. The overarching questions that motivated and guided our study concern how science learning could combat this sense of disorientation, help make the future more perceptible and make young people feel they can have power over not just their personal futures, but also the futures of the big issues like climate change. We were especially interested in the potential for science learning to contribute to young people's personal development as responsible citizens and, more specifically, we wanted to see how learning about climate change could activate young people to think of themselves as agents in society.

In reaching these goals, science education would help young people to perceive future global scenarios as something imaginable, a virtual space that they can influence and shape through their actions in the present within a social system. It would create fertile ground for involving them in significant science learning processes oriented to lay the foundations to face the new global challenges. However, we realized that to pursue such goals, science education needed inspiration and resources from other fields that are oriented to investigate the issue of future thinking and could thus enrich science education with new concepts and tools.

The research field that explicitly addresses these issues is the field of futures studies (e.g. Bishop et al., 2007; Kousa, 2011; Rickards et al., 2014). This interdisciplinary field typically involves sociologists, philosophers, historians, political scientists, psychologists and economists, but also scholars and practitioners from the arts, natural sciences, technology and engineering. Futures studies investigate trends and other sources, patterns and causes of change and stability in order to develop foresight and create possible, probable and desirable future scenarios. The field works to shed light on ways in which future thinking relates to human worldviews, perceptions and emotions. The main goal with futures studies is to use foresight to orient actions in the present that can influence and create preferable or desirable futures. Recently, futures scientists have turned their attention to education. "Teach the future" is a nonprofit organization that professionals in futures studies built to bring foresight and future thinking to schools so as to teach students "to think critically and creatively about the future and develop the agency to influence it" (www.teachthefuture.org).

From futures studies, we adopted the concepts of "future-oriented activities" and "futures thinking." Furthermore, we applied the argument to "futurize" education to science education. We proposed incorporating future thinking skills into school science, including scenario thinking, systems thinking, thinking beyond the realm of possibilities, action competence, and skills to manage uncertainty and complexity (Branchetti et al., 2018; Levrini et al., 2019; Tasquier et al., 2019). Another key concept we borrowed from futures studies, and re-shaped within science education, is the notion of "perception of the future." Young people's perception of the future is central to our project and refers to how young people feel the future as distant or near, abstract or concrete, as something they have influence over or not, and how they relate the future back to themselves and the present.

Adopting perspectives from the field of futures studies and integrating them into science education, we present an empirical study on how science education can develop students' futures[(1)] perceptions and skills to manage the uncertainties of the present with an eye on the horizon. Before entering the description of the context, the methods and results of the study (§5, 6, 7), we frame the topic of futures within the field of science education and illustrate the main concepts we borrowed from futures studies (§2), then we present both the background of the study (§3) and the European project within which the study is situated (§4).

2 Framework: Integrating futures studies into science education

Science education implies significant demands as well as opportunities for addressing concerns over young people's futures perceptions discussed above. First, the great majority of students' fears and deterministic, utopian and dystopian future views are connected to science and technology (Carter & Smith, 2003). Secondly, along with the growing realization of the unsustainability of our contemporary way of life, taking action and contributing to change has been taken up as an important aim of school science (European Commission, 2015; Hodson, 2003; Mogensen & Schnack, 2010). In the recent position paper by the OECD (2018), Anticipation (foresight), Action and Reflection (AAR) were given a key role as dimensions of the compass needed to navigate the complexity of the current world. They imply the development of skills related to the capacity to push imagination forward, to take responsibility to participate in the world and consciously influence events and circumstances for the better. This call for fostering students' AAR connects futures thinking to agency, since "agency involves the idea of projection and implies anticipation" (Cuzzocrea & Mandich, 2016). Indeed, our thoughts about future opportunities influence our actions and sense of agency in the present. Consistent with this, the OECD's learning framework (OECD, 2018) promotes the need for futures thinking by suggesting that the competencies for engaging with the world should be learned in a sequenced process of reflection, anticipation and action. Responsible actions emerge through reflective and anticipatory processes.

The current COVID-19 pandemic crisis is further uncovering the gravity and urgency of global challenges - global warming, migration flows, spread of diseases. Science education is called upon to provide citizenship skills to enhance the role and responsibility of individuals towards global social phenomena (Blandford & Thorne, 2020). More specifically, this emergence emphasizes the need for science education to incorporate the action competence approach which aims to make students more conscious of the decisions and actions they take in society (Jensen & Schnack, 1997). This approach has been used particularly to develop democratic education and environmental and sustainability education pedagogies, but it has not yet been widely incorporated into science education (Mogensen

& Schnack, 2010). One compelling exception is that of Hodson (2003), who introduced agency into science education research, with particular attention to social activism.

Science education has seen societal issues addressed through the establishment of socio-scientific issues (SSIs) as part of science curricula worldwide (Zeidler et al., 2005). SSIs have proven successful in rendering science learning more relevant to students, promoting critical thinking and value-laden dialogue, and addressing the nature of science and the complex connections between science, technology, society and environment. While SSIs usually do include some consideration of the short-term future, it has been argued (Branchetti et al., 2018; Levrini et al., 2019; Buntting & Jones, 2015; Paige & Lloyd, 2016) that specifically developing long-term future thinking skills in science education has the added value and the potential to broaden students' perceptions of future possibilities and afford them opportunities to develop agency and identity, ultimately preparing them to confront the complex, uncertain and sometimes hopeless future.

The approach presented in this paper assumes futures studies as part of its framework and aims to turn its basic ideas into principles for designing teaching activities in science (Branchetti et al., 2018). Research in the field of futures studies has shown that important images of the future have a positive effect on an individual's life (Bell, 1997; Rubin, 2000). Emotions like hope and fear run through our future thinking. Focusing on threats narrows down thinking, while adopting a perspective of hope encourages one to see alternatives and opportunities (Lombardo, 2010). Climate educators have pointed out the importance of realistic hope, not to be confused with unrealistic optimism, in fighting the climate crisis (Ojala, 2012; Pihkala, 2017). Experts in futures thinking have also argued that stories about alternative future scenarios diversify our views of future possibilities and thereby prepare us for the future that will become the present (Bishop et al., 2007). Not questioning 'automatic' future thinking patterns keeps us from considering alternative futures (Hutchinson, 1996) and thereby effectively manifests the dominant future narrative as reality, limiting possibilities for the realization of alternative futures for society. Furthermore, education is not immune to efforts to "de-futurize" sociopolitical discourse in order to reduce people's anxiety towards the future (Bergmann, 1992). Scholars have warned of the dangers of such a de-futurizing approach: "Whether in relation to our schools, our societies or our species, when taken-for-granted ways of thinking about the future are left unexamined, a closure of horizons occurs – futures are foreclosed and 'inevitabilities' are confirmed as 'realism'" (Hutchinson, 1996, p. 48). Indeed, typical atemporal or historically-oriented ways to teach science are ineffective, if not harmful, for building students' perceptions of the future and the possible roles of science in it. What further exacerbates this problem is that limitations in future thinking skills do not apply only to students, but also to educators (Rubin, 2000).

In spite of all the reasons presented here for elaborating the concept of future in school science, such pedagogies have not been widely adopted by science education until a few recent initiatives (Branchetti et al., 2018; Buntting & Jones, 2015; Jones et al., 2012; Levrini et al., 2019; Paige & Lloyd, 2016; Barelli et al., 2018; Tasquier et al., 2019). Australia, however, is an interesting exception, since the future has been an explicit aspect of curriculum and pedagogy there since the 1960s. Working in this context, Paige and Lloyd (2016) developed an educational approach that integrates the future dimension into science learning to enable students to develop a broader future-oriented perspective that impacts on many aspects of their lives. They stress the necessity to identify and envision alternative futures that are more socially and environmentally fair and sustainable. Our work builds partially on this approach, among others, discussed below.

To pursue the goal to integrate a future dimension into science learning, we decided not only to borrow concepts and good practices from the field of futures studies, but also to explore the connections between such concepts and science itself, exploiting the resources that science offers to conceptualize some core ideas of futures studies, like uncertainty, projection, scenario, and prediction. In the following, we describe the key concepts and activities from the field of futures studies that we selected as resources to enrich science education with future thinking, highlighting the connections with scientific concepts and epistemologies. In Section 4, concerning the presentation of the structure of the module, we will show concretely how they can be intertwined with scientific concepts and epistemological issues in teaching-learning activities.

Futures studies typically seek to create a holistic or systemic view of complex societal phenomena, and employ a range of approaches, models and methods from social sciences as well as physical and life sciences and applied sciences. The assumption of the complexity of the phenomena implies a challenge to deterministic conceptions of time, in which past, present and future can be viewed simply as an ideal linear chain of events. In complex systems, deterministic prediction in a quasi-classical sense still works only within specific space–time scales (e.g. models of weather forecasting), while at bigger space-time scales (e.g. climate models) the concept of projection becomes necessary and a range of many possible future scenarios is considered as opposed to a single, unique future. Uncertainty in projections implies a move from the idea of "one future" to the idea of a multiplicity of futures: futures become a set of possible scenarios, where a scenario is "a coherent, internally consistent and plausible description of a possible future state of the world" (Levrini et al., 2019, p. 2650). Understanding the plurality of futures means to disengage from deterministic future views, identify and question assumptions to develop alternative scenarios and visions of the future, and understand that small changes at a certain point can become major changes over time.

To appropriate the idea of futures as a set of possible scenarios, especially given the unprecedented levels of uncertainty and change currently seen in society, necessitates the development of specific skills (e.g. Anderson, 2010; Rickards et al., 2014): scenario thinking, systems thinking, thinking beyond the realm of possibilities, action competence, and skills to manage uncertainty and complexity. In Levrini et al. (2019) we showed that the science of complex systems provides concepts and tools that allow us to frame part of these future thinking skills scientifically. In the following, we summarize key ideas that are necessary to frame the presentation of the module and the data analysis and define the terms we will use.

The first terms that we adopted from futures studies refer to the conceptualization of different visions of the future: what the future could be (possible futures), what it should be (preferable or desirable futures), what it is likely to be (probable futures) (Voros, 2003; Hicks & Holden, 1995; Masini, 1993). According to Voros (2003), possible futures include all the futures we can imagine – including even unlikely possibilities, while the plausible futures concern cases that could happen according to our current knowledge of how things work now (physical laws, sociological models, technological knowledge, etc.). Among the plausible futures, some – named probable futures – are considered more likely to happen according to the current trends, a sort of extension of the present. To visually represent the distinction between plausible, possible and desirable futures, Voros (2003), reformulating an idea introduced in 1994 by Hancock and Bezold, proposed the "futures cone" (see Figure 1).

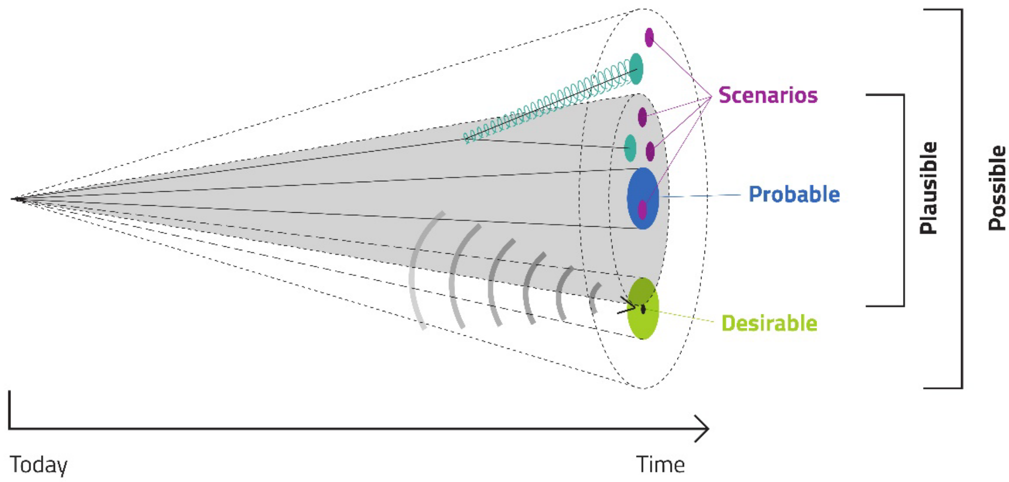

Figure 1 The futures cone.

The cone represents something more than a list of terms and this added value gains special relevance in the light of what has been happening in the COVID-19 pandemic. The first point is that just because a scenario has low plausibility does not necessarily mean it should be abandoned. There can be sudden and unpredictable events that drastically change the path connecting the present to implausible future scenarios. The cone shows that even improbable scenarios are still hypothetically reachable. This is not a science fiction perspective: the last decades have shown drastic, hard-to-predict changes in our societies in different dimensions (technological, societal, economic, health). A second point of strength of the cone is that it makes visible a reversal of the usual direction of thinking from the present to the past. It shows that there is more than one seriously possible pathway to connect future scenarios backwards to different intermediate points in time. This encourages the line of thinking that actions, choices, and events can make the difference in influencing what future scenario will become real. It places value on agency and imagination of desirable scenarios, rather than dismissing them from the beginning as highly improbable at that moment.

This last remark opens the way to different visions of the futures (possible, plausible, desirable) and the fact that they imply different orientations and different techniques and approaches for the design of their respective scenarios. In particular, probable future scenarios are usually built on forecasting techniques which aim to point out trends by analyzing the past and the present. These methods are still epistemologically oriented mainly by a deterministic, predictive, linear approach to improve the accuracy of predictions. Possible (or alternative) futures scenarios are built by searching for weak signals that can lead to deviation in trends and/or by questioning the basic assumptions behind the mainstream trends. Finally, the preferable and desirable future scenarios are built on foresight and anticipation techniques. Foresight, unlike forecast (which goes from present to future), starts from a future and traces it to the present through back-casting activities in order to design possible actions that can realize a desirable scenario. Hence, foresight implies the ability to build a vision by detaching from the current situation. Unlike forecasting that deals more with trends and prediction of probable scenarios, foresight introduces the subjective notion of preferable futures. These engage people at the emotional and more generally affective level (values, beliefs, attitudes) and require them to reflect on their values, desires and their cultural points of view. As we stressed in the introduction, taking care of these dimensions is crucial with young people embedded in our complex society of acceleration. Moreover, foresight, taking into account the social, political and economic implications that every decision has, allows futures thinking to go far beyond the purely conceptual scientific aspects of scenario building, making scenarios richer, more realistic, and bringing the future of the world closer to one's personal future.

As the AAR model from the OECD stresses, the sense of foresight and anticipation is strongly related to taking actions in the present to create such scenarios. The ability of foresight and back-casting, then, is linked to the concept of action competence. Action competence activities in education, based on Roth and Lee (2004), are activities designed "to trigger awareness of the plurality of perspectives at stake in decision-making processes, and so support students in expanding their ethical consideration as they go forward making intentional decisions and taking deliberate actions" (Branchetti et al., 2018a, p.21). In practice, this can be pursued by encouraging participation in a key action that implies the development of agency. In this paper and, consistent with a future-oriented perspective, when we talk about agency, we refer to the capacity to take responsibility for global challenges, take part in decisions and consciously influence events and circumstances in order to realize a desired future scenario. A key notion, introduced by researchers investigating obstacles to and strategies for the development of agency, is that of *exposure*: to be able to choose an alternative future and become an agent of it, an individual has to be exposed to it (Elder, 1995).

3 Background of the study

The study presented here connects to the European Erasmus+ project "I SEE – Inclusive STEM Education to Enhance the capacity to aspire and imagine future careers" (2016-2019), described in detail in the following section. I SEE developed secondary level science education to equip and empower students to face uncertainty and contribute meaningfully to their own and global futures (Branchetti et al., 2018). The project was preceded by two studies where the concept of 'future-scaffolding skills' was coined and tentatively defined. The idea was born as a *sensitizing concept* (Glaser & Strauss, 1967) in a pilot study that the research group in Bologna carried out in 2015, paving the way for an approach concerning the infusion of the future dimension within science education.

The origin of the concept is described in the foundational article on this approach (Levrini et al., 2019), where the authors report the preliminary results of the implementation of a module designed in 2015 to *futurize* science education. The core of the paper is a description of the theoretical framework, built to value futures perspectives within science education as*: an intrinsic and fundamental aspect of science, a crucial dimension of our society of acceleration and for personal engagement with contemporary challenges* (Levrini et al., 2019). A second pilot study elaborated on the concept of future-scaffolding skills and their distinction as structural/systemic and dynamical started to emerge (Tasquier et al., 2019). The two pilot studies concern the implementations of a future-oriented module on climate change with secondary school students (grade 11, 12). During these implementations a trend emerged (Levrini et al., 2019): the teaching module impacted students' thinking of futures mainly in the sense that the activities contributed to '*widening* their perspectives' and 'making the future become *approachable.'* More specifically, students described a sense of *widening* of their future horizons, wherein the activities gave them the opportunity to enlarge: (1) the knowledge of the topic they believed to have acquired; (2) the range of possible actions that could be taken; (3) the range of new ways of thinking and looking at problems; and (4) the awareness and confidence in their own potential and role as agents. With respect to a sense of approaching, futures were perceived by students as more *approachable* in several senses: (1) closer in time, in the sense that the year 2030 went from being far and unimaginable to conceivable as a set of possibilities; (2) closer to reality, in the sense that they became approachable through concrete actions in the present; (3) closer to themselves, in the sense that the futures moved to within their reach and they found ways to see themselves as agents of their own futures (Levrini et al., 2019).

The analysis of final individual interviews pointed out that the approach appeared promising for developing specific skills to structure ways of thinking about the present, the futures and their back-and-forth relations. The emergence of this bunch of skills represented the origin of our *future-scaffolding skills*, and of our first draft definition of them as "skills that refer to the capability of organizing knowledge in the present, imagining futures and moving dynamically and consciously, back and forth, globally-locally, between different 'space' and time dimensions" (Tasquier et al., 2019). Furthermore, from students' discourse, two types of future-scaffolding skills started to be recognizable: *structural skills*, skills to organize the impelling, fragmented and chaotic reality of present; and *dynamical skills*, skills that let students dynamically navigate between local details and the global picture, across future, present and past, as well as from an individual to a collective dimension.

The resulting set of markers about *widening* and *approaching* and about *structural* and *dynamical skills* represents the research-based tool that guided the data analysis we will report in this paper. Thus, the data analysis we will present here regards a second stage in the process of characterizing and operationalizing future-scaffolding skills. We anticipate that the set of data analyzed in this paper will enable us not only to revise and refine the operational markers, but also to build, finally, an operational definition of future-scaffolding skills.

The data come from the implementation of a module on climate change designed within the I SEE project and tested in an international summer school with 24 secondary school students coming from Finland, Iceland and Italy. In the following section, the teaching module is described so as to contextualize the implementation.

4 The I SEE project and the climate change module

The "I SEE" project was formed by a strategic partnership (8 partners) among three secondary schools, two universities, an environmental NGO, a teachers' association and a private foundation coming from four European countries: Italy, Finland, Iceland and the United Kingdom. The partnership set out to study the possibilities of bridging futures studies to science education and implementing future-oriented activities in science classes. The main goal was to address the issues in science education posed by global unsustainability, the uncertainty of the future, and social acceleration as described above. One aim was also to find ways to make STEM education personally, socially and professionally more relevant for young people and their futures.

To foster the development of students' future-scaffolding skills in science education, several teaching-learning modules were designed. Every module was built on a scientific, future-relevant topic that was also of genuine interest to students. The module on climate change was developed in close collaboration by all partners, and its structure is described in more detail below. Following the climate change module, three more I SEE modules on carbon sequestration, artificial intelligence, and quantum computing were designed by the local communities of practice formed in Italy, Finland and Iceland by the partners. Besides the four implemented teaching-learning modules, the partnership produced a module guide for implementing and/or developing further modules, a report on case studies, and recommendations targeted at educational institutions. All these intellectual outputs are publicly available on the I SEE website (www.iseeproject.eu).

4.1 The structure of the module

The overall module structure is presented in Figure 2, and it comprises five phases described below.

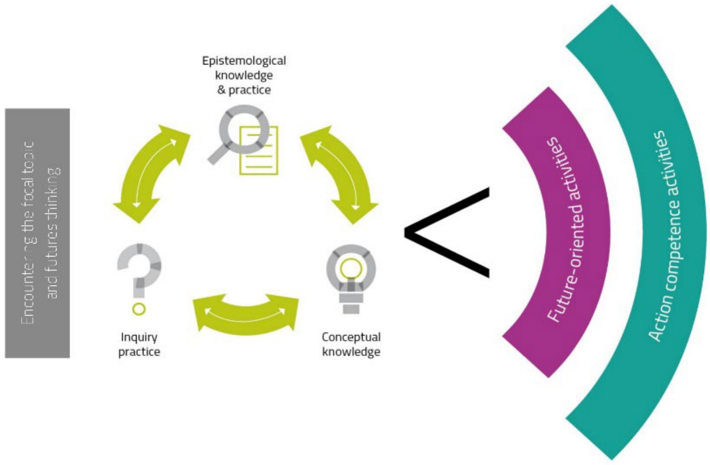

Figure 2 Structure of an I SEE module. The parts from left to right are: encountering the focal topic and futures thinking; engaging with scientific conceptual-epistemological and inquiry activities (the central, cyclic part); bridge activities (the black "less-than" symbol); future-oriented activities (the first, purple arc on the right); and action competence activities (the second, turquoise arc on the right).

In the figure, the different teaching-learning phases are represented by different colors. They are, from left to right: *encountering the focal topic and futures thinking; engaging with scientific conceptual-epistemological and inquiry activities; bridge activities; future-oriented activities;* and *action competence activities*. Below, each phase is briefly described together with a more detailed insight about their content from the climate change module.

Encountering the focal topic and futures thinking: At the beginning of the module, students encounter the focal topic (the leftmost part of Figure 2) and they are given an overall introduction to the topics that will be dealt with in more detail later in the module. In the specific case of the climate change module, encountering activities are represented by plenary lectures on climate change and futures studies given by experts. The lectures give students not only an overall picture of both focal topics, but also help them to begin to see the interconnections between science and future.

In the lecture on climate change, a global-local vision was outlined by the speaker, Dr. Carlo Cacciamani from the Regional Environmental Protection Agency (ARPA, Italy). He introduced the notion of climate as a complex system and presented a comparison between phenomenological evidence and the disciplinary tools of climatology (e.g. climate models, scenarios and IPCC charts). Furthermore, the implication of climate change on the societal dimension was discussed by introducing specific language and concepts like risk, vulnerability, mitigation, adaptation, etc.

The lecture on future was carried out by Dr. Peter Bishop, a futurologist from Teach the Futures, Inc. Dr. Bishop introduced the framework of futures studies and the difference between prediction, forecast and foresight. He also showed the "futures cone" (Voros, 2001) (see Figure 1). Again, specific language and concepts were introduced, like scenarios and their construction, forecast vs. projection, back-casting, values, anticipation, vision, etc.

Engaging with scientific conceptual-epistemological and inquiry activities: In the second set of activities, the students were guided to engage with the three dimensions of science: conceptual knowledge; epistemological knowledge and practice; and inquiry practice (the central, cyclic part of Figure 2). Conceptual knowledge refers to the disciplinary content knowledge, while epistemological knowledge and practice refer to epistemic practices such as modeling, arguing, and explaining. Inquiry practices are skills such as posing questions, formulating hypotheses, designing inquiry, triggering peer-to-peer interaction, recognizing modeling as a process of isolating a particular phenomenon, and moving from models to experiments and vice versa. These three dimensions of science are expected to give students a sense of disciplinary authenticity (Kapon et al., 2018).

After encountering the focal topic in the climate change module, students were guided to develop and practice scientific, conceptual/epistemological, and inquiry skills in various hands-on laboratory activities. They were asked to form their own hypothetical model of the greenhouse effect that was then revised and developed based on the results of experiments. The concepts particularly addressed concerned: the importance of the concept of stationary equilibrium in terms of absorbance and emission by objects; the property of transparency; the construction of a relationship between the change in the absorbance of the atmosphere (due to the variation of a certain type of gas) and the temperature. The epistemological dimension requires particular attention to scientific practices such as making predictions, observing, and analyzing data, modeling, argumentation and explanation. Among the epistemological practices, some activities were carried out to stress the difference between: sequential linear reasoning and equilibrium reasoning (necessary for explaining the greenhouse effect to avoid falling into the misconception of entrapment); linear and circular causality (necessary for building towards the concept of feedback loops).

Bridge activities: Building a bridge between science and futures, these activities connect scientific, conceptual and epistemological knowledge and practice with the issue of future. Bridge activities are presented in Figure 2 as the black "less-than" symbol. This kind of activity has the main goal of introducing the scientific concepts and epistemological topics in which the future-oriented are scientifically grounded. Indeed, as we anticipated in the framework, future thinking techniques have a scientific background combined with a set of activities that aim at involving people at a more emotional and affective level. The bridge activities provide the students with such concepts and promote the development of scientific skills that cannot be taken for granted and are very useful in the last part of the module, where students are engaged in future-oriented activities.

In the climate change module, students were first introduced to the perspective of complexity and its basic concepts. Then, students were guided to carry out concrete activities concerning the analysis of scientific texts or videos through tools, like conceptual maps. Specifically, in this bridge activity students were required to: read and interpret a scientific text (using their acquired knowledge) in order to recognize and reformulate the logical and causal structure of the phenomena described in it and translate them into a map; indicate causal reasoning behind the identification of positive and negative feedback on the map; switch from local specific feedback to its location in the global map.

The fundamental idea behind these activities was to make students aware that future is intrinsic to science: the processes of building predictive models and causal structures for explaining the unknown represented constitutive epistemic practices of science. Students were guided in becoming aware that science has developed various models of causality, from the linear models of Newtonian mechanics to probabilistic models elaborated within 20th century science. Quantum physics and the science of complex systems are extremely rich sources of concepts, like space of possibilities, future scenarios, projection instead of prediction, uncertainty, feedback and circular causality, that can be suitable for development into skills for thinking and talking about the future (Levrini et al., 2019; Branchetti et al., 2018; Barelli et al., 2018).

Future-oriented activities: The I SEE teaching and learning approach includes at least two types of future-oriented practices (the first, purple arc on the right in Figure 2) that can be developed with the aim of turning knowledge into future-scaffolding skills and competences:
a) activities inspired by futures studies to imagine the cone of possible, plausible, desirable future scenarios;
b) exposure activities to enlarge the imagination about the range of possible actions that can be taken in the present as citizens or as future STEM professionals.

In the climate change module, the future-oriented activities included the societal dimension in the idea of complexity. Students were involved in an analysis of a complex citizenship context of urban planning, taking into account the social, political, and economic implications that their decisions have. In this exercise, they were asked to apply the concepts coming from futures studies and compare and discuss different future scenarios for an imaginary city. The future cone, with the ideas of plausible, possible and desirable futures, as well as the concepts of scenarios, anticipation and back-casting, became concrete in this activity. Finally, in order to enlarge students' knowledge about the complexity and the multidisciplinarity of the topic of climate change, an exposure activity was carried out through a panel discussion with experts from various climate-related fields (physics, engineering, environmental activism, and policy). The panelists engaged in a discussion with the students about their career paths, their professional ambitions and other driving factors.

Action competence activities: These activities (the second, turquoise arc on the right in Figure 2) aim to trigger awareness of the plurality of perspectives at stake in decision-making processes, and so to support students in expanding their ethical considerations as they go forward making intentional decisions and taking deliberate actions. This final phase of the module also calls for students to synthesize ideas and practices they have encountered and engaged with throughout the whole pathway.

To begin to transform knowledge and practices acquired into skills in action in the climate change module, students were required to project themselves into a desirable future in 2030. They worked in groups to plan and articulate their own success story of how they managed to solve a critical problem related to climate change by using the back-casting method (Börjeson et al., 2006). To empower the students, they were asked to take a role in the change, and at the end, they presented their scenario to the whole group.

5 The study

5.1 Research questions

With the study we sought to answer the following questions:

1. *To what extent and how did the module impact students' perception of the future and the development of future-scaffolding skills?*
2. *How can students' perceptions of the future be conceptualized by future-scaffolding skills?*

The first research question is empirical and to some extent contextual. The second one is theoretical and aims to provide a contribution to *futurize* science education and show what future thinking skills science teaching and learning can develop.

5.2 Context and sample

The module on climate change was implemented in the context of the I SEE summer school, which was held in Bologna (Italy) from June 5th to 9th, 2017 at Opificio Golinelli. The module was implemented according to the following schedule:
a) Encountering activities: plenary lectures (3 hours);
b) Conceptual, epistemological and inquiry activities led by the Finnish team (8 hours);
c) Bridge activities led by the Italian team (8 hours);
d) Exposure, future-oriented and action competence activities led by the Icelandic team (12 hours, including students' presentations).

The participants in the summer school were 24 students (16-19 years old), eight from each partnering school: the Normal Lyceum in Helsinki, the Lyceum A. Einstein in Rimini and the Hamrahlid College in Reykjavik. The students were selected by the teachers involved in the project, according to the same criteria and method, which were co-determined by the project partners.

Students ages 16 to 19 years old received an application form to fill in case of interest. The form included a description of the summer school and a specific statement that we were not searching for STEM persons, but students with different interests, perspectives and attitudes towards STEM subjects.

On the basis of the filled-in forms that the teachers received, eight students were selected according to the criterion to have internally heterogeneous groups with respect to gender, school performance

in general and in science in particular, cultural background. All the students had to competent in English.
In spite of the same criteria of selection, there was a difference in the students' interest the call raised each country. The Finnish teachers had to choose the participants out of a smaller group of applicants than Icelandic and Italian teachers.
As a result, the sample was formed by:

- 8 Finnish students, among which 4 females and 4 males, 3 strongly interested in STEM and 5 not particularly interested;
- 8 Icelandic students, among which 5 females and 3 males, 5 strongly interested in STEM and 3 not particularly interested;
- 8 Italian students, among which 4 females and 4 males, 4 strongly interested in STEM and 4 not particularly interested.

As well as the cultural differences among the three groups, the whole group included students with a rich and diversified cultural background. At least six students, as well as speaking English, were bilingual because of the different languages spoken by one or both parents.

5.3 Methods and tools of data collection

Inspired by Design-Based Research and its theoretical orientation, we collected data to be qualitatively analyzed. In particular, we gathered data to cover four dimensions of student learning: conceptual, epistemological, future-oriented and action competence. Data were collected through a large variety of tools for checking against one another, for corroborating evidence and for evaluating the extent to which all evidence converges (Anfara et al., 2002). In the following, we briefly describe each tool used for data collection which are reported in their entirety in the annexes:

Students' essays on future. Before the beginning of the summer school, the students were asked to write an essay to "Imagine a summer day in 2030 and try to think yourself in the place where you wish to live." In order to better investigate students' imagination of the future in terms not only of surrounding environment and changes, the students were asked to answer some questions describing their dreams, concerns and fears. The students emailed the essays a week before the summer school. During the summer school they were asked to revise their initial essays noting the differences. See Annex 1 for details.

Students' questionnaires. At the end of each day of the summer school, the students were asked to fill in a questionnaire aimed to check and evaluate the quality of the knowledge they acquired along the different activities of the module. It was composed of multiple choice and open-ended questions and required about 15 minutes to complete. Examples of questions were (see Annex 2 for details): Before attending the I SEE summer workshop, how familiar were you with [specific scientific or future-thinking concepts of the day]? To what extent did today's I SEE summer workshop activities help you to develop your knowledge and understanding of [specific scientific or future-thinking concepts of the day]? For the activities that you gave a low/high ranking please explain why.

Focus groups. At the end of the last day of the summer school, three focus groups were conducted with students divided by country. The focus groups were led by teachers; the researchers were only present as observers. The protocol was semi-structured to leave space for students to freely express their thoughts about their experience at the summer school; to facilitate the active participation of everyone, they were allowed to talk in their own languages. Focus groups were audio-recorded, then translated to English by the researchers of each country. The protocol is reported in Annex 3.

Individual interviews. Some days after the summer school, individual interviews were carried out by researchers without the presence of the teachers. As for focus groups, students were interviewed in their own languages and interviews were audio-recorded. The interviews were carried out in the week after the summer school. The first part of the interview asked for students to comment on the overall structure of the summer school. Examples of questions were (see Annex 4 for details): Was the summer school as you expected? Was the programme difficult/easy/interesting/boring?). In the second part, students were asked to compare the pre-assigned essays about the future to the revision they made during the summer school and to reflect on the role of the summer school in shaping their imagination of the future. Examples of questions were: Has your perception of futures changed during the summer school? Have you gained tools for thinking and building your future? What are the words or the concepts you learned during the summer school that you found most powerful for thinking about the future?

Audio- and video-recordings of the summer school activities. All the activities of the summer school (experiments, working group, lectures) were audio and video recorded. In particular videos were taken of the students' final presentations in which the different groups told their own success story of how they managed to solve a critical problem related to climate change.

5.4 Methods of data analysis

As already mentioned, the data analysis stemmed from what emerged in two previous studies, where students were engaged in similar future-oriented activities (Branchetti et al., 2018; Levrini et al., 2019; Tasquier et al., 2019). In those contexts, the students described their experience as a process that led them to *widen* their views about the future and to feel the future as more *approachable*; moreover, they mentioned structural and dynamic skills that, in our view, appeared to be good candidates for becoming recognizable as future-scaffolding skills.

Although stemming from those studies, this case cannot be considered as a third-round implementation within an iterative design because the module was too different from the one implemented in the previous ones and the context was as well too different because of its international and multicultural character. Hence, we decided to use only the markers we had developed in previous studies as *lenses* to read and analyze the data. In other words, we decided to analyze this new data set to check if and how phenomena of widening and approaching and structural and dynamic skills development were visible in this new context and, if so, what further inferences could be made with respect to the impact of the module on students' perceptions of futures and the development of skills. To this purpose, we articulated the data analysis in the following phases.

5.5 Phase one: data organization and top-down analysis

The first phase concerned the construction of our database, by organizing all the sentences coming from all the data sources in which the students described the effect of the module on their future perception and their skills development. When one sentence included multiple nuances, it was attributed to more than one category. The goal was to check whether the previously defined phenomena of widening and approaching also appeared in these data and if they are effective to describe the change of students' perception of future. Methodologically this meant carrying out a top-down analysis where the possibility of further bottom-up evidence was kept open.

The organization of the data according to the structural and dynamical categories was less easy but appeared to make sense. However, in the triangulation among the authors of this paper who were all involved in the data analysis, and in our de-briefing about the table, some issues came out in the coding and, in particular, in the definition of widening, approaching and skills markers. In particular, the triangulation pointed out the presence of:

a) redundancies - widening and some approaching categories tended to overlap;
b) obscurities - different researchers gave different interpretations to the same category;
c) operational ineffectiveness of categories' descriptions - the descriptions of the categories did not always seem adequate to point out operational markers; that is, markers to guide a researcher to read out, analyze and select the data that can belong to the various categories.

As a result of these inadequacies researchers were not always able to understand the way another researcher codified the data.

5.6 Phase two: Revision and reformulation of the categories and of their markers

The second phase concerned the revision and reformulation of the categories, as well as a refinement of the database, according to new markers. This phase led to the first important result we will report and discuss in the next section: the list of categories and operational markers as not only able to code the whole corpus of data but also to capture the main reactions of the students to the climate change module. This result is particularly relevant from a theoretical point of view since it not only provides a list of future-scaffolding skills, but also the operational tools to recognize them in students' discourses or actions.

5.7 Phase three: Data reduction and analysis

The third phase concerned the construction of visualization tools (graphs and histograms) to represent the results and allow us to see, in an aggregate form, patterns or emergent properties. In order to interpret the graphs, two research workshops were carried out. In the workshops, the researchers (the authors of the paper and other teacher-researchers involved in the I SEE project) were asked to describe what they saw in the graphs. All the comments were discussed and the most relevant were selected. The data analysis was triangulated by researchers coming from all the three countries in order to check the reliability of data interpretation. The intelligibility and reliability of the comments were checked in two different respects: a) they were evaluated as reliable if they could be supported also on the basis of arguments coming from other studies, b) they were evaluated as intelligible if they were effective in capturing and reflecting what the observers (teachers and researchers) perceived in the atmosphere during the summer school.

This third phase led to another important result: an aggregate picture of the impact of the modules on students' perception of future and a distribution of the skills students perceived themselves gaining and stated so in the data. From this analysis, one comment can be anticipated since it opened up the problems that we addressed in the fourth phase of the analysis. Because the graphs about the skills refer to data self-reported by the students, they only give a picture of what the students perceived and explicitly claimed about the skills they developed during the summer school. They do not necessarily mean the real development of those skills. Thus, a second important question is: are we able to check whether the skills perceived and claimed by the students are real skills they developed? If so, how?

5.8 Phase four: Checking hypotheses through case studies analysis

In order to address the issue of how to compare the skills declared with the skills for which evidence was found in the data, we decided to consider the videos of the final presentations that the students created in groups in the last phase of the summer school. The students were asked to use back-casting to tell their success story of problem solving in the form they preferred: a video, a picture, or a theatrical presentation. The final presentations were video-recorded and analyzed. We selected two illustrative cases and, after the video analysis, we compared the skills that were put into action by the groups and the skills that the members of the groups stated in interviews, focus groups or questionnaires. The comparison between stated and activated skills supports our hypothesis that the module indeed impacted students' development of future-scaffolding skills. Further, more detailed methodological aspects are reported in the next section where the results of the analysis are described and discussed.

6 Data analysis and results

6.1 Result 1 – The categories and the operational definition of future-scaffolding skills

The first result of the analysis concerns the refinement of the markers that enable the identification, monitoring and evaluation of the impact of this approach on students' perceptions of the future and on the development of future-scaffolding skills. In particular, the analysis led us to recognize that, through the module, most students experienced a widening of possible ways of thinking, roles of stakeholders, and actions to address the future-oriented scientific issue (in the case of the summer school, the issue of climate change). Moreover, they perceived the future as approaching them, since it became closer in their imagination, their present and their growth path. In particular, we recognized six different nuances of widening and three of futures approaching, whose operative descriptions are reported in Table 1, each of them alongside an example of students' sentences[(2)]. With respect to the table of widening presented in the previous studies (Levrini et al., 2019; Tasquier et al., 2019), the most significant change consists of having distinguished between the widening in disciplinary STEM knowledge about the issue (Wid0) and in the amount of knowledge on future thinking (Wid1). We decided to name the first widening as Wid0 since it does not explicitly refer to a change in future perception but rather to a change in the amount of students' disciplinary STEM knowledge. The definitions are "operational" since their description includes specific markers to code the data and indicate which student's discourse presents them.

Table 1 Operational description of the markers for the change of future perception by using examples of students' expressions. The last column shows, for each category, the number of students displaying it (total number of students: 24).

WIDENING		
Description of marker	**Examples of students' sentences**	**Fraction of students**
(Wid0) Widening in the amount of knowledge about the disciplinary contents of the FoSI (Future-oriented Scientific Issue)	The summer school made me better understand what we are talking about when discussing climate change, what the problems actually are. (SM23)	21/24 (88%)
(Wid1) Widening in the amount of knowledge on future thinking, provided by futures studies	I thought it was very cool to be introduced to the idea of the three futures: the expected, the plausible and the preferred. I had not given this concept any thought before and the two lectures drove the point home exceptionally well. (SM12)	13/24 (54%)
(Wid2) Widening in the range of new ways of addressing and looking at the FoSI	I've learned that the future is complex, and it has to be viewed from many points of view. I've learned to look at every topic from many different viewpoints and to think of many solutions for the future. This is something that is not taught at school that much, in my opinion. (SF4)	10/24 (42%)
(Wid3) Widening in the range of possible roles of non-expert stakeholders (e.g. citizens, policy-makers) for addressing the FoSI	Everyone has to take care of global development. The world I want to live in includes a government that listens to sensible people who have important things and ideas to share. Everyone has to become aware of climate change and are living eco-friendly lives while trying to diminish the damage that was done in the past. (SF13)	6/24 (25%)
(Wid4) Widening in the range of possible roles of expert stakeholders (STEM researchers and other experts in the field) for addressing the FoSI	You do not usually hear much about people who are active in environmental research. Now I know there are people working to improve this situation. (SF17)	11/24 (46%)

(Wid5) Widening in the range of possible actions, strategies and concrete solutions that can be undertaken to address the FoSI	I've gotten to learn about some solutions I hadn't heard of before, for example I didn't know biofuel was an option. (SM9)	15/24 (63%)
APPROACHING		
(Ap1) The future became closer to students' imagination, i.e. from far and unimaginable, it became thinkable to them	Now when I think of the future, I see a beautiful sunset. It's such a beautiful word and the three horizons, it makes them all beautiful. (SF10)	5/24 (21%)
(Ap2) The future became closer to students' present reality, i.e. it became approachable through concrete actions that can be undertaken in the present	Perhaps I will in general consider what I do […] Because I got to know how big my carbon footprint is. So maybe I'll think of my everyday choices more and how to do things better. (SF2) I'm interested in taking action to protect the environment. For example, I'd like to minimise the amount of food waste. (SF4)	18/24 (75%)
(Ap3) The future became closer to students' personal, social, professional growth path, i.e. it became within their reach and they found ways to see themselves as agents of their own future	This showed me, opened up a door for me. I always wanted to go into this field, but now I know I can. It increased the chances for me that I go into STEM. (SF13)	16/24 (67%)

The second very important result is the identification of skills that we organized in two macro-categories: structural skills (St), which are abilities to organize pieces of knowledge and build systemic views (an intentional and conscious process of scaffolding); and dynamical skills (Dyn), which are abilities to navigate across the complexity of knowledge, without trivializing the relations between local details and global views, the relations between past-present-future, and the role of individual and collective actions.

We interpret these categories of skills as future-scaffolding skills: structural skills are indeed needed to build a rational scaffolding of the topic by recognizing the causal, temporal, and logical relationships among them. They constitute the base upon which to navigate across the scaffolding for developing scenarios, visions and creative ideas for the future, which are the object of dynamical skills. In Table 2, we report the description of future-scaffolding skills markers alongside examples of students' expressions.

Table 2 Operational description of the markers for the future-scaffolding skills by using examples of students' expressions. The last column shows, for each category, the number of students displaying it (total number of students: 24).

STRUCTURAL SKILLS		
Description of marker	**Examples of students' sentences**	**Fraction of students**
(St1) Distinguish between disciplinary details and the comprehensive picture of the FoSI	Each experiment added a piece of knowledge that at the end of the path of the experimentation occurred to recreate the complete picture of the situation. (SF17)	4/24 (17%)
(St2) Unpack the FoSI in simpler, addressable parts	I have learned that if you want to achieve something it is good to divide it [the task] in smaller pieces. (SM1)	2/24 (8%)
(St3) Recognize causal relationships	I found helpful these activities […] because they made me understand suddenly the reasons beyond the feedback process. The biofuel activity in my opinion really worked because we got into the process that involved considering the consequences in the future as the main task. (SF19)	6/24 (25%)
(St4) Recognize multiple aspects of the problems and their relationships (e.g. distinction between problems, objectives, solutions or between pros and cons) for structuring proper thoughts and articulate strategies and plans for solving them	The biodiesel issue has positive and negative aspects: we have to consider both of them. It involves ethical, social and political issues. […] I think future revisioning, problem analysis and calculating carbon sequestration are really helpful activities to have a complete view of the dimension of a problem, and to start thinking about the solutions and not only about the effects. (SF19)	6/24 (25%)
DYNAMICAL SKILLS		
(Dyn1) Move from thinking locally to thinking globally (and vice versa)	We really need to think globally, even though we start with ourselves and our cities, our countries. (SF15) We should always take into account that global conditions affect local conditions, so everyone should care about the whole global development. (SF19)	7/24 (29%)
(Dyn2) Move from thinking at the present to thinking at the future (and vice versa)	In the future, but starting from now, we will make a choice about what kind of society and cities we want to live [...] Be careful with alternative fuels or other kinds of natural energy sources: look at their impact on the environment as far in time as you can. (SM23)	8/24 (33%)
(Dyn3) Move from thinking at the individual to thinking at the societal community and/or the other stakeholders	Everybody should just realize that we need to cooperate. We are not going to succeed if there are only a couple of people. (SF2) When I have thought about the future, I have always just seen myself. I have never thought about the people around me or what is happening around me. (SF10)	11/24 (46%)

(Dyn4) Think creatively for imagining new possibilities and concrete actions	They got the group to use everyone's imagination and come up with all sorts of ideas. It also got us to think critically and try to find plausible solutions to current environmental problems, which was good. (SF13)	6/24 (25%)
(Dyn5) Balance the need of aspiring and desiring with that of keeping feet on the ground	I know now that it is alright to dream big, these things are happening in real life, real days but yeah we still have a long way to go and I realized that I thought a lot about changes we needed to make in the world but not about how we make those changes, how we change all the things that are bad. (SF15)	6/24 (25%)
(Dyn6) Think in a multidisciplinary way, breaking down the barriers among disciplines	Humanistic and technological aspects were very intertwined ... ethics was interspersed with technological development. (SF19) It was also a brilliant example to see that in the world of jobs you need to develop transversal skills, you can no longer be too attached to the 'engineer', for example, and be just an engineer. You need to be able to collaborate with various experts and be able to understand and help them. (SM22)	4/24 (17%)
(Dyn7) Move from thinking in terms of necessity to thinking in terms of multiple possibilities	I always get really stressed when I think about the future, just what I am going to do in the future, but thinking like this, because I had never realized, I have always thought about maybe one scenario that could happen, which is often one in which everything falls apart totally, but to think from the perspective of many possible futures, like the cone and the models even for what could be outside of the cone. There is so much that could happen. I thought that was really interesting. Just to think of all the thinkable (possible) possibilities, find the most likely, but still, you know, to think of the most unlikely because there are still chances that they could happen, too. (SF10)	5/24 (21%)

6.2 Result 2 – The impact of the I SEE climate change module on students' perceptions of futures and on their skills

After a revision of the categories and their operational description, we moved to the second stage of the analysis aimed to aggregate the data and see whether patterns emerged. For this purpose, a series of graphs have been built by counting how many appearances were categorized in each category, formed in the previous stage, when considering the whole corpus of data. The graph in Figure 3 shows the distribution of the widenings, approachings and skills perceived by the students. This graph was not obtained by counting all the occurrences for all the categories, but by counting for each category how many students showed at least one sentence that could be identified as a category's occurrence.

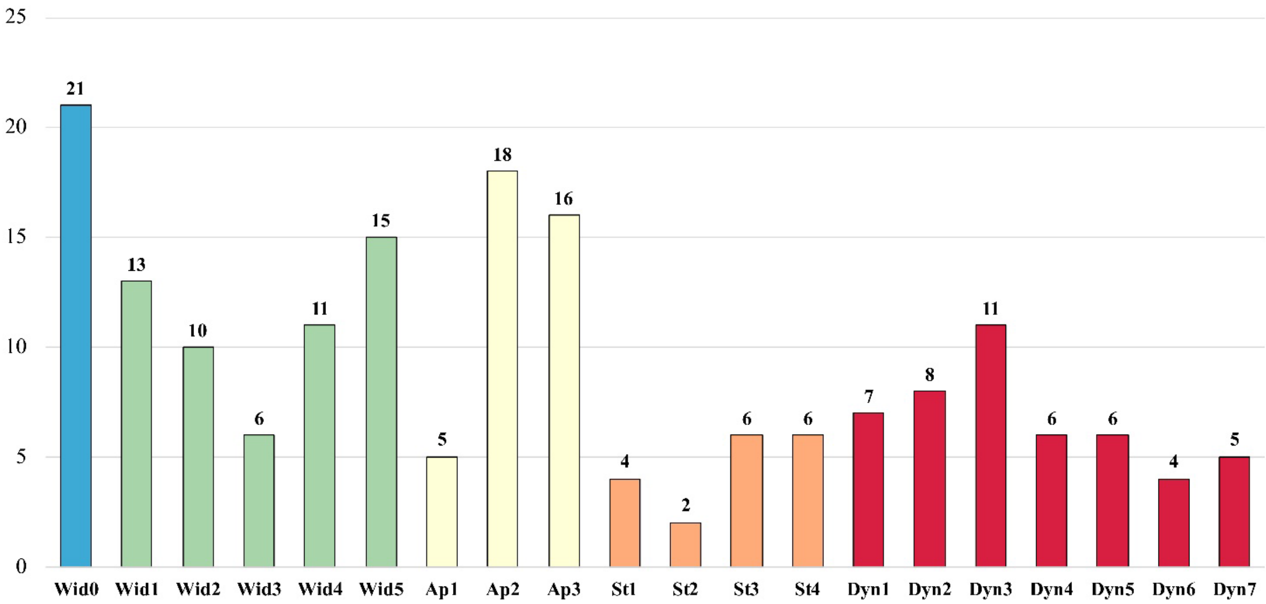

Figure 3 The total appearances of the widenings, approachings and skills perceived (total number of students: 24).

The graph shows that all the categories are well represented and the data are distributed. Within approaching, Ap1 (*The future became closer to students' imagination, i.e. from far and unimaginable, it became thinkable to them*) appears less frequently with respect to the other two types of approachings that are very well populated. This low occurrence looks reasonable, since it refers to mid-long term thinking and the "imagination dimension," which are particularly difficult to develop in a short time.

Frequencies of occurrence cannot be compared between structural and dynamical skills due to the difference in difficulty of describing them. The dynamical ones are easier to describe even without specific questions in the data collection tools since they require a narrative style. On the other hand, description of structural skills can require specialized language. On the basis of these remarks, the fact that many students show structural skills is in itself a very interesting and positive result.

Concerning the dynamical skills, we notice that Dyn 4-5, like Ap1, refer to a personal, private and imaginative dimension and the fact that they appear is an impressive result for a one-week course. The dynamical skills that appeared to be slightly more prevalent (Dyn 1, 2, 3) refer to dimensions that belong to public debate and, for this reason, it makes sense that the students may be more responsive and more reactive to these aspects.

In order to create a detailed picture and see how these skills were distributed among all the individual students, we built a graph (see Figure 4) that shows the distribution of widening, approaching and skills, organized by student. The figure shows the profiles of the groups that students were in for the final activities of the summer school.

The final project entailed analyzing a climate problem of their choice, imagining in detail a "success story" in which the problem is solved in the future, and finally back-casting the success story from the future to the present. The 23 students of the summer school (one student did not participate in the group work) formed 5 groups, named according to the titles of their success stories. The groups were formed in a bottom-up way, according to students' desires, sharing of values, and interest in a certain topic. At the start of the final project, students were asked to decide one climate problem they wanted to work with and write it down on a little piece of paper. The teacher collected the papers and put the students in groups based on common interests. The groups were blended in terms of gender and country; however one group was formed only by males.

Figure 4 The distributions of the widening, approaching and skills perceived per student (SF means Student-Female; SM Student-Male) arranged according to the groups. One student (SF3) did not participate in the group work.

From this graph we can say that both widening and approaching are widespread over the students (by covering all three countries) and only one case does not show any widening and approaching (SM1).

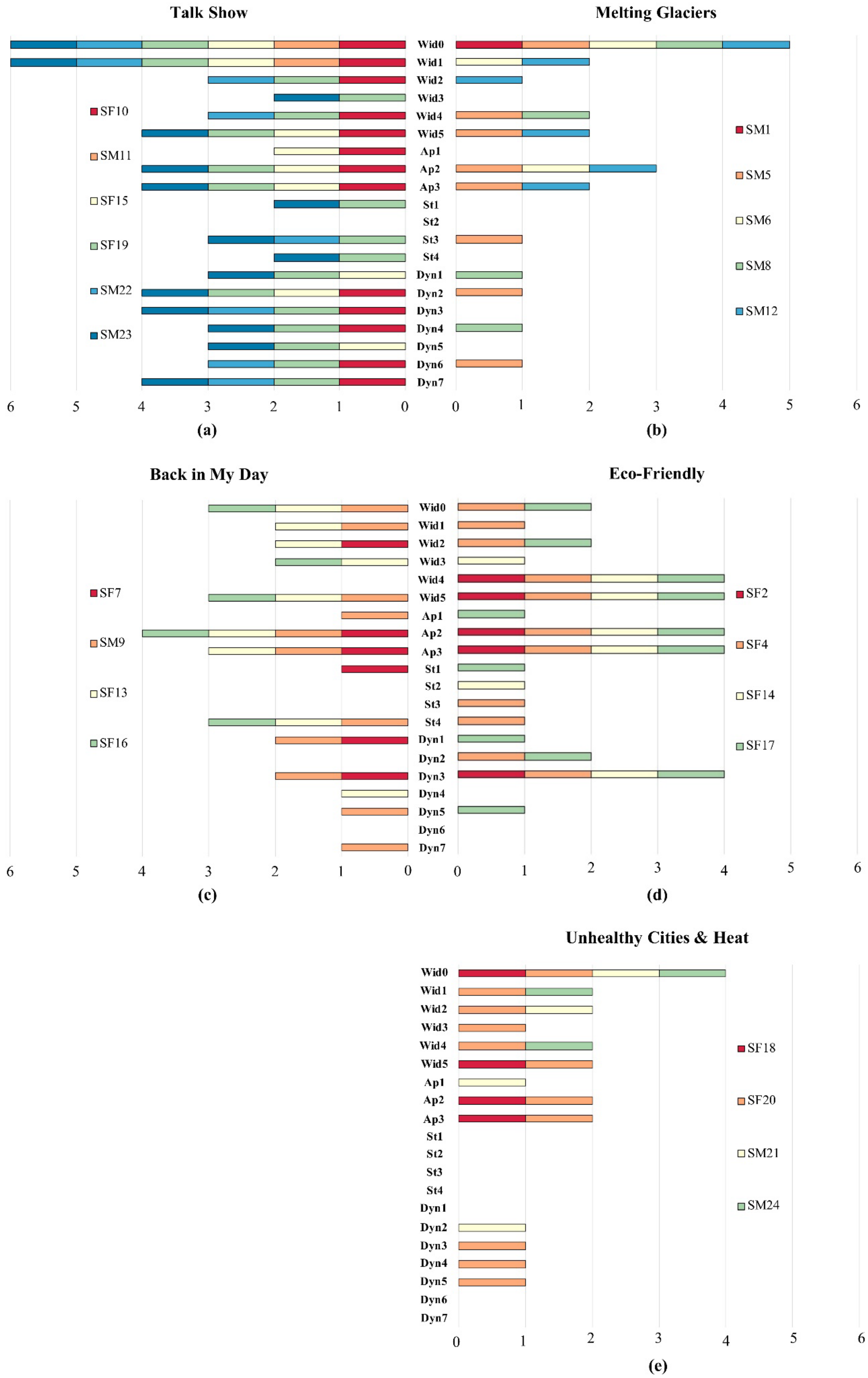
Talk Show
SF10
SM11
SF15
SF19
SM22
SM23
(a)
Melting Glaciers
SM1
SM5
SM6
SM8
SM12
(b)
Back in My Day
SF7
SM9
SF13
SF16
(c)
Eco-Friendly
SF2
SF4
SF14
SF17
(d)
Unhealthy Cities & Heat
SF18
SF20
SM21
SM24
(e)
Wid0
Wid1
Wid2
Wid3
Wid4
Wid5
Ap1
Ap2
Ap3
St1
St2
St3
St4
Dyn1
Dyn2
Dyn3
Dyn4
Dyn5
Dyn6
Dyn7

Figure 5 Profiles of the groups.

This graph can also be read to infer students' profiles. Furthermore, and particularly useful for the next step of the analysis, it can be the basis to build what we call "group profiles." As we will see, the outline of groups' profiles from these data about students' perception is a crucial step for passing to the third stage of the analysis aimed to check if the skills perceived are indeed skills developed by the students.

These profiles appear very different: in a rather evident way, the graphs for the groups "Talk Show," "Back in My Day" and "Eco-Friendly" show a richer distribution of widening, approaching and perceived skills than the graphs for the groups of "Melting glaciers" and "Unhealthy Cities and Heat."

6.3 Result 3 – The impact of the I SEE module on students' development of future-scaffolding skills

As anticipated above, in order to check the real development of the skills perceived by the students, we decided to consider the videos of the final presentations and to sort out the skills that emerge directly from students' actions and discourse. We decided to analyze in-depth the final outputs of two of the groups, "Talk show" and "Melting Glaciers," since their profiles appeared very different from each other (Figure 5).

A first consideration emerging from the analysis is that some skills emerged from the structure of the work while others emerged from sentences pronounced by an "actor." Even if in these latter cases the markers can be traced in specific sentences said by one student, we can assume that the choices made for the final projects were based on shared decisions within the groups.

"Talk Show" group

The group formed by SF10, SM11, SF15, SF19, SM22 and SM23 decided to structure their final presentation as an episode of a talk show: "Our history." During the show, set in 2030, five individuals were invited to talk about their roles in and their views about the so-called fifth revolution, the revolution of electric transport. The guests were an environmental geologist (SF10), the researcher that designed the technology at the basis of the realization of faster charging and longer lasting batteries for the vehicles (SF15), the politician that encouraged the revolution (SM22), the owner of an electric car company (SM11), and a supporter of carbon fossil fuels (SM23). In the following, we illustrate in more detail the students' presentation, highlighting the moments in which we recognize signs of change of future perception (Wid and Ap) and of future-scaffolding skills development (St and Dyn).

From the very beginning of the presentation we recognize Wid3 and Wid4 in the choice to involve a wide range of stakeholders, both expert and non-expert, in the discussion. In the first part of the show, SF10 and SF15, the two scientific characters, explain to the audience the novelty of the technology behind the new functional electric vehicles with respect to old fuels: in particular, we recognize Wid0 when SF10 defines what fossil fuels are and why they are non-renewable sources of energy. Going beyond the disciplinary widening, the group shows a Wid1 when SM22, the politician, illustrates the timeline of the fifth revolution, echoing the idea of back-casting introduced by futures studies. Also Wid5 can be traced in different moments of the students' presentation, in the different types of actions carried out by the different stakeholders (e.g. launch of the innovative fuels factory, start of pro-climate policies).

The approachings are well represented throughout the whole presentation. For example, SM22 says that at the beginning they "did not see what to do and where to go" to address the issue, expressing that they felt the future far and difficult to imagine. But this perception changed when they "started to consider new opportunities and imagine multiple possibilities" (Ap1) and began to think in terms of concrete actions, as the ones presented in the timeline mentioned above (Ap2).

As for the structural future-scaffolding skills, we recognize St2 when SF19 shows a map the group made showing what they considered difficult, medium and easy topics related to the problem of energy supply (e.g., respectively: air transport, sustainable housing and private vehicle transport). The structural organization of the problem allowed them to unpack a big and multifaceted issue (the energy supply) and to identify, among the parts, a problem (private transport) that was addressable for them.

Causal reasoning (St3) is also strongly traceable in the students' presentation. About this point, in the case of this group, we have to say that the linearity of causal links prevails in more complex reasonings. The entire story told during the show is a story of success: from the research on batteries to the investment by the government, from the incentives for buying new electric cars to the ban on circulation of fossil fuel-powered vehicles. Even the promotional video produced by the students and shown at the beginning of the presentation contains very linear and apparently naïve statements like "electric cars were being developed and finally people started to use them, and the conditions of the earth improved." These claims can be justified by the context in which they are told: a television show with the goal of informing and convincing the audience about the social, economic and environmental value of the fifth revolution. Indeed, linear statements are typical of propaganda: they have to be persuasive and easy to understand, hence they often emphasize the message they want to communicate via a clear selection of the contents and of the events. However, during the show there are some moments in which the linearity of this story of success is softened. We trace signs of this in the recurrence, especially in SF10 and SF15's speech, of the verb "contribute," when they explain the role of the new batteries in improving the conditions of the earth.

The non-linear dynamical skills are present during the entire presentation. The same "idea of longer lasting and faster charging batteries for electric cars," expressed by SF15, is a manifestation of the development of Dyn4, as a creative concrete action to influence the future. Also the concept of dream and utopia is well-balanced by the group with a concreteness that shows the need for keeping your feet on the ground (Dyn5): this is expressed by SF19 when she illustrates the problem of air transport, explaining that the solution would consist in a “sustainable way of travelling, because we cannot stop travelling.”

But the core of the presentation is the discussion between SM23, the pro-fossil fuels protester, and SM22, the politician who mainly supported the fifth revolution. SM23 is convinced that the past with its “good old days” was better than the present thanks to fossil fuels. His arguments, centered on his present interests and needs, are summarized in the following sentence: “when we used fossil fuels we were happier, vehicles were faster so we used to get home earlier, whereas now you have to take your electric car and it takes a lot to go, because you are very slow. I could run on the street and make races with other people, nowadays you can’t.” The ironic spirit of SM23’s speech becomes more evident in the second part of his intervention when, sneering, he recalls “the smell of fossil fuels… when you woke up in the morning, you opened the window and it was perfect. Also the noise of engines was music for my ears, these noiseless vehicles are just stupid.” With his quasi-comic tone, SM23 seems to make fun of simplistic analyzes like his own: trapped in the present without any view on the future, in the local small world in which one lives and in the contingent needs or pleasures of individuals.

Then comes SM22’s speech that starts with a completely different tone telling the story of the revolution. This story began under uncertainty, since they “did not see what to do and where to go” but, after having “considered new opportunities and imagined multiple possibilities,” they started to act. In his intervention, SM22 not only illustrates the timeline of the fifth revolution but also tells his personal story: “initially I was a small politician, but I felt a great responsibility toward these people and their wish for a greener world and a greener future for our children.”

From this debate between SM23 and SM22, that we have here summarized, we recognize in a peculiar way the emergence of three other dynamical skills, Dyn1, Dyn2 and Dyn3, which involve a transition between two ways of thinking. SM23 represents the starting point – thinking locally, in the present moment and of individual contingencies and needs – while SM22 personifies the realization of the skills – thinking globally, in the future and of society as a community.

“Melting Glaciers” group

The presentation carried out by the group formed by SM1, SM5, SM6, SM8, SM12 was centered around the problem of melting glaciers and the students’ idea for mitigating it which was to cover all glacial surfaces on Earth with aluminum foil. One student, SM1, conducted most of the presentation and another one, SM12, participated in a few moments; the other three students were silent during the presentation.

In the following, we illustrate in more detail the students’ presentation, highlighting the moments in which we recognize signs of change of future perception (Wid and Ap) and of future-scaffolding skills development (St and Dyn). Generally, the presentation was weak in both aspects: to show this, we argue how not only some perceptions did not change and some skills were not developed, but also how even *opposite* attitudes can be traced.

The only widening displayed in the presentation is the disciplinary Wid0, when SM1 talks about the physics behind the melting phenomenon, including the albedo effect taught during the summer school. There is no sign of any other widenings; there is no reference to any method or concept from futures studies (no Wid1) and the story is told only from a scientific-engineering perspective, without any contradictory opinion and without introducing diverse ways of tackling the issue (no Wid2). Strictly related to this point, in the presentation the concept of stakeholder, both expert and non-expert, is completely absent (no Wid3/4). Even after an explicit question, the only professional role that SM1 foresees for all the members of the team is the "engineer" working for a "company."

We cannot find any marker for approaching in the presentation. We think that this is due to the central idea elaborated by the group: it is so unfeasible and science fiction that it seems not to activate any change in the perception of future, which remains far from the students' imagination and present reality.

The structural skills are mainly expressed through the causal map drawn by the group to highlight the "things that contribute to the sea level rising." Even if the students identify some of the factors leading to this phenomenon (and we can recognize traits of St3), they do not mention nor represent in the map the positive feedback loop at the basis of the melting of glaciers. The causality is linear and there is no sign of taking into account more complex reasonings.

But the most critical point of the presentation is represented by the absence of dynamical skills. On the contrary, there is a sort of resistance displayed by the students to thinking globally (no Dyn1). Their idea of covering the glacial areas with aluminum foil was elaborated with a very local objective: this is evident when SM1 explains that the cost of such an intervention should be covered by "a coalition of Antarctic countries or of areas where there are glaciers," as if the problem of melting glaciers only affected areas with glaciers and was not a global problem.

Comparison of the two groups

The comparison of the two cases shows an interesting and substantial relationship between the perceived skills and the skills actually put into action. In particular, we observed the graphs in Figure 5, showing the profiles of skills perceived by the students from the two groups. For both groups, not all the widenings, approachings and skills perceived by the students (those in Figure 5) could be recognized in action in the final presentations. However, substantial differences can be identified. In Figure 5, most categories were populated by many students of the "Talk show" group, while the graph for the "Melting glaciers" group shows many categories in which only one student appears. This is particularly manifest for structural and dynamical skills that seem to disappear in the transition between students' and group profiles for the "Melting glaciers." We can also explain this with the above-mentioned fact that the "Melting glaciers" presentation was mainly led by one student (SM1), with a few contributions by SM12. In particular, SM5, the student who in Figure 5 (graph for "Melting glaciers") is the most present in the categories, remained silent for all the presentation, as well as SM8, who showed refined dynamical skills. It does appear that the disappointing scarcity of widenings, approachings as well as structural and dynamical skills in the "Melting glaciers" presentation was partly caused by unsuccessful group dynamics when planning and carrying out the presentation.

On the contrary, the "Talk show" group not only had more uniform students' profiles (in Figure 5 graph for "Talk Show", only SM11 appears in two categories, while the other students are comparably present in the other categories), but also allowed each student to contribute to the final presentation. In this regard, the format chosen by the students for the presentation – a talk show in which all the students were actors of their own roles – also really helped to let each voice emerge.

Regardless of variation due to differing group dynamics, there appears to be a correspondence between skills perceived and skills in action. This supports the effectiveness of the markers we chose to capture a phenomenon that really occurred: the I SEE climate change module appeared to impact on some students' perceptions of the future and on the development of future-scaffolding skills. Now that we are able to identify the learning outcomes that we can produce, it will also be easier to improve the modules and address the problematic cases that we recognized in this implementation.

7 Discussion and conclusions

Two research questions have been addressed in this study. As an answer to the first question, *to what extent and how did the module impact students' perception of the future and the development of future-scaffolding skills?*, we showed that the I SEE climate change module confirmed the widening-approaching phenomenon that were already captured in two previous studies. The new set of data allowed us to refine the categories and their descriptions. Furthermore, the study contributed to recognition of future-scaffolding skills that can be developed through science education. In particular, we were able to list and describe both structural and dynamical skills. Moreover, a process of data analysis showed that the skills described by the students were in fact enacted in the last activity of the module.

The contribution of the study to capturing the impact of the module on students' futures perceptions and on the development of future-scaffolding skills allows us to move onto a more theoretical level and address the second question, concerning the characterization of future thinking in terms of future-scaffolding skills: *How can students' perceptions of the future be conceptualized by future-scaffolding skills?* In a previous study we defined these skills as structural and dynamical skills to construct visions of the future that support possible ways of acting in the present with an eye on the horizon (Levrini et al., 2019; Tasquier et al., 2019). Thanks to the analysis carried out in this paper, we have now a list of structural and dynamical skills, as well as an operational and detailed description that allows a researcher to recognize them in students' discourse and actions. This result has a broad impact that goes far beyond the specific study. We started from a wide analysis of the current situation, and from authoritative studies in sociological and science education (Benasayag & Schmid, 2006; Eurobarometer, 2015; Heikkilä et al., 2017), that all emphasize the need to support the younger generation in dealing with the uncertainties of our time, to develop a sense of realistic hope and active orientation toward the future (cf. Ojala, 2012; Pihkala, 2017), and to develop a compass for navigating the complexity of current society. This compass, as the OECD stresses (2018), requires capacities of Anticipation (foresight), Action and Reflection. In our study we not only showed that all these recommendations can be turned into instruction design in science education, but also that this compass can be built. Even more, the list of future-scaffolding skills and the description of the markers to identify them show in detail what can be fostered through science education and how that can be recognized and measured. These skills appear particularly relevant to address the challenges of this fragile, complex, global and fast-changing world, such as spread of diseases, global warming and migration flows, that require science education to provide a contribution to enhancing the role and responsibility of individuals towards global social phenomena (European Commission, 2015; Hodson, 2003; Mogensen & Schnack, 2010), by keeping an eye on the horizon.

In the context of global crises, indeed, long-term futures tend to be conceptualized separately from the future of one's own life (Leahy et al., 2010; Threadgold, 2012) and studies like ours show that it is both possible and necessary to make short-term individual perspectives interact, in a back and forth dynamic, with mid- or long-term collective and global scenarios.

From this perspective and as further contribution from the study, we propose viewing Tables 1 and 2 not only as lists, but as a comprehensive picture of goals that science education can and should prioritize to make science relevant from a personal, social, vocational point of view. Both the distinction between structural and dynamical skills and the types of dynamical skills that emerged from students' discourse are, in our opinion, fruitful and useful in the era of frenetic standstill and knowledge fragmentation, discussed in the Introduction. Epistemic skills of selecting and organizing pieces of knowledge in comprehensive pictures are fundamental, as well as the skills of moving back and forth from details to global views (Dyn1), from the present to the future (Dyn 2), from an individual to a collective dimension (Dyn3), from imagination to actions (Dyn4), from desire and aspiration to reality (Dyn5), from one discipline to another (Dyn6) and from a sense of necessity to a sense of multiple possibilities (Dyn7).

Considering the core structure of the module and the data collected about the evolution of students' approaches to futures, a further message we can take from the study is that future-scaffolding skills are not simply soft or transversal skills, independent of content and discipline. These skills can be nurtured and developed within disciplines, science in particular: for example, the modeling approach that science has developed to make predictions and build scenarios can and should become a foundational part of science curricula. From this point of view, the approach and the emergent picture of skills as goals can be used to orient educational policies, recommendations for curriculum design, as well as new research approaches so as to make science a real context to prepare students for current and future challenges. In particular, the approach of the module seems to bring not only students' personal futures but also societal and global futures within students' reach, and thereby alleviate the challenges in future perception especially regarding current global crises like the coronavirus pandemic and the climate crisis.

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Notes

1. *[on p.4]* We intentionally refer to "the futures" in plural throughout because, as futurologists point out, there is no single future but multiple possible future scenarios (see §2 for discussion of futures studies).
2. *[on p.18]* In order to maintain anonymity, students' names were coded using numbers, but gender distinction was maintained. In this paper, when reporting students' sentences, we will refer to them as SF (Student-Female) or SM (Student-Male). In the coding, references to the country have also been omitted to ensure anonymity.

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