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The I SEE project: An approach to *futurize* STEM education

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Abstract
In the world where young people feel that the future is no longer a promise but a threat, and science and technology are sources of fears and global problems, a challenging task for education is to support students in imagining a future for the world and for themselves. The aim of the EU-funded project "I SEE" is to create an approach in science education that addresses the problems posed by global unsustainability, the uncertainty of the future, social liquidity and the irrelevance of STEM education for young people. This way, we believe, STEM education can support young people in projecting themselves into the future as agents and active persons, citizens and professionals, and open their minds to future possibilities. In this paper we propose a teaching and learning approach for futurizing science education, and describe how that approach was used to develop the first I SEE module implemented in summer school in June 2017 with students from three countries. In sum, the I SEE teaching and learning approach consists of three stages and learning outcomes connected to each of them: encountering the focal issue; engaging with the interaction between science ideas and future dimensions, and synthesizing the ideas and putting them into practice. The middle stage of the model is the main part, involving future-oriented practices that turn knowledge into future- scaffolding skills. We describe four kinds of such future-oriented practices: a) activities to flesh out the future-oriented structure of scientific discourse, language and concepts; b) activities inspired by futures studies or by the working life and societal matters; c) exposure activities to enlarge the imagination about possible future STEM careers; and d) action competence activities. We conclude the paper by reflecting on our experiences of the implementation of the climate change module with upper secondary school students.

Key words: futures studies, STEM, upper secondary, action competence, climate change education, future-scaffolding skills

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***Perspective**: Educational visions*
***Fields**: Earth Life Support Systems*
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The future as an educational issue

The current unsustainability of systems vital to earth's functioning, both natural and social, has important implications for education, and has elicited responses from different fields including environmental education, education for sustainable development, post-normal science and futures studies, among others. The uncertainty of the future of our planet that this 'systemic global dysfunction' represents necessarily casts into question the grounds on which education is based, its values and purpose (Lotz-Sisitka, Wals, Kronlid, & McGarry, 2015). If the role of education is to prepare learners for their future, how can education prepare learners for an uncertain future? In light of the challenge to existence these global crises pose, the role of education becomes preparation for uncertainty itself. We synthesized this goal with the term "futurize", that is the counterpart of the notion of "de-futurizing", introduced the first time by Bergmann (1992) to describe a special feature of political discourses: to reduce people's anxiety and fears, the future is often deprived of some of its main features, like uncertainty, possibility, and impossibility to determine what will happen once and for all. On the contrary, several experts in futures studies have suggested that the unprecedented levels of uncertainty of the contemporary world highlight the need for preparing people to be surprised (e.g. Anderson, 2010; Rickards, Ison, Fünfgeld & Wiseman, 2014). As science educators, we set out on this collaboration to discover how science education could respond to the call of the future, developing a pedagogy that acknowledges the tension young learners feel for the future and addresses the personal, social and professional irrelevance of much of current science education practice. We asked ourselves, how can we "futurize" science education?

The future is by definition uncertain, and crises have threatened the future before. However, the nature of current global systemic dysfunction is so ubiquitous that young people feel not only that the future is no longer a promise but a threat, but also that science and technology, far from saving the world, are sources themselves of fears and global problems (Benasayag & Schmidt, 2006). Furthermore, contemporary society is marked by such accelerated, constant change and social fluidity that our sense of ontological security is compromised (Giddens, 1991). This liquidity (Bauman, 2001) is a source of anxiety and frenetic standstill (Rosa, 2013), which is further exacerbated by economic and social crises that limit young people's educational and professional possibilities. Indeed, the European Parliament Flash Eurobarometer showed that young people feel marginalized or excluded from economic and social life by these crises and that their country's education and training system is not well adapted to the world of work (EP EB395, 2014; Eurobarometer, 2015). In this environment, the daunting task for education is to support students in imagining a future for the world and for themselves. Science education, which must play a critical role in understanding and addressing the global crises, also has the task of overcoming the barrier of student lack of interest in and bias against STEM subjects (Tytler, 2014; EC/EACEA/Eurydice, 2012).

Science education does not currently address these issues fully or holistically, and this challenge is the premise for the I SEE project (**I**nclusive **S**TEM **E**ducation to **E**nhance the capacity to aspire and imagine future careers; https://iseeproject.eu): to create an approach in science education that addresses head-on the problems posed by global unsustainability, the uncertainty of the future, social liquidity and the irrelevance of STEM education for young people and their future. The scale and scope of the challenge requires deep innovation in pedagogies. It requires STEM education to stretch itself outside its traditional bounds and acknowledge students' fraught relationship with the future and with science and technology. Educators may take on new roles to help students to cope with their anxieties about the future of the world and their lives. Such a pedagogical approach will necessarily be reflexive about its purpose and values. It will involve facilitating students in gaining competence to understand the post-normal complexity of science (e.g. Turnpenny, 2012) and the complex systems that are highly significant for their futures. Thus it also becomes relevant for students in multiple ways: in their personal, societal and professional lives, now and in future (Stuckey, Hofstein, Mamlok-Naaman & Eilks, 2013). STEM education can then support young people in projecting themselves into the future as agents and active persons, citizens and professionals, and open their minds to possibilities, both for the world and for themselves.

After a contextualization of the project, this paper presents the approach we used to futurize STEM education. We firstly describe the design process we followed and, secondly, the result of our design: the structure and the learning outcomes of the module we designed and implemented in an international summer school. The model of an I SEE module is an outcome of the project and, here, it represents the original part of the paper whose goal is not to present the first empirical results but to position the I SEE design approach within the literature. Comments about our experience and our implementation will close the paper.

Futures Studies, STEM and the search for strategies to "futurize" STEM education

In order to futurize STEM education, relevant references for our project are the methods and concepts developed in the field of *Futures studies* (FS in the following). FS is an interdisciplinary field that was born in the 1950s after the World Wars, when groups of policymakers, conditioned by the threat of an atomic war, began to investigate the relation between present and future events. The main goal of this field is to help people to build future scenarios in order to suggest actions in the present, looking at several stakeholders. A turning point was, in 1968, the foundation of the Club of Rome, that pursued the aim to analyze changes in society and establish limits to growth in all fields (economy, industry, technology, etc.), so as to make human life sustainable (Meadows et al., 1972). In the last 60 years FS has become an important field of investigation and many techniques and approaches to the construction of future scenarios have been developed; some ideas and methods are inspired also by science and mathematics (Bell, 2003).

While in the last decades FS has expanded and involved more and more professionals and institutes, experts argue there is a worrying lack of attention to this issue in education (Bell, Preface to Hicks, 2006)[1]. Hicks (2006), talking about future as the missing dimension in education, proposed reflections on the topic and activities to foster FS attitudes at school. Among several possibilities, to face the problem from an educational point of view, we decided to rely on one of the perspectives proposed by Bell (2003), according to whom the futurists' main goal is to teach people that the future is an open horizon, a dimension of freedom that could be creatively explored through the development of skills. Visions of the future can be constructed and they can support possible ways of acting creatively and consciously in the present with one's eye on the horizon. In this general frame, STEM can play a role in conceptualizing the difference among different approaches to the construction of scenarios. For instance, a scientific approach allows us to clarify the meaning of the key concept of *foresight* that starts by imagining possible futures and, through *back-casting* activities, returns to the present to design possible actions that can foster the achievement of a desirable scenario, unlike forecasting, which is based on the elaboration of futures scenarios moving from the present to the future (Börjeson, Hoöjer, Dreborg, Ekvall & Finnveden, 2006). The main difference lies in the assumption of a deterministic or a complex relationship between present and future(s), moving only forward or also backward, from possible futures to the present. A crucial point is that there are several ways to deal with the future(s) that are grounded also in different scientific paradigms and imply different approaches to the construction and analysis of future scenarios (Levrini, Tasquier & Branchetti, under review). In our project we value in particular the distinction made between

[1] In STEM education an interesting approach grounded in FS is developed by Paige and Lloyd (2016).

possible, plausible and preferable futures and the concepts of *foresight* or *anticipation* (Voros, 2003), as we will show in section "Future-oriented practices" below. The intrinsic link with scientific concepts opens up a great opportunity for science educators to get inspiration from the field of FS in terms of key ideas and techniques to "play" with future scenarios in a productive way, but also to face this challenge stressing the important role played by science in formulating and approaching the problem of future(s).

The I SEE project

Purpose

The project is formed by a strategic partnership 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 goal of the project is to design innovative approaches and teaching modules to foster students' capacities to imagine the future and aspire to STEM careers. The goal is not only to develop professional skills but also to foster students' identities as capable persons and citizens in a global, fragile and changing world. To this end, we have recognized specific skills that should be developed through science education in school and out-of-school contexts. Particularly, the project aims to outline a STEM education approach centered on the concept of what we call *future-scaffolding skills*; that is, skills that render science learning relevant – personally, socially, professionally and scientifically – and enhance students' capacity to aspire, envisage themselves as agents of change, and push their imagination towards future careers in STEM. This concept is quite new and we started to develop it in a preliminary study that originated the I SEE project (Levrini et al., under review). On the basis of this preliminary study, future-scaffolding skills were defined so as to include, for example, *strategic thinking and planning, risk taking, thinking beyond the realm of possibilities, managing uncertainty, creative thinking, modelling and argumentation.*

In order to develop future-scaffolding skills within STEM education, the partnership develops innovative teaching-learning modules on cross-cutting fields, including climate change, artificial intelligence and quantum computing, which are likely to be relevant in students' futures, both at the personal, vocational and societal level (Stuckey et al., 2013). The partnership is composed of a multidisciplinary research group in STEM education and the activities are designed within collaborations between researchers and teachers in science (physics, chemistry, geology, computer science, etc.) and mathematics.

Modules build on the action competence approach in which students become more conscious of the decisions and actions they take (Jensen & Schnack, 1997). The 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 case of use of the action competence approach in science education, in which students were given the opportunity to identify a local issue and define what and how to investigate to address the issue, found that it afforded multiple modes of participation to students, so had the unexpected benefit of supporting diverse student abilities and interests, particularly with respect to culturally-related differences (Roth & Lee, 2004). This project will explore this potential further to see what action competence can contribute to creating science education that has inclusion and cultural diversity built-in into its design. Action competence will be moreover combined with "exposure", i.e. the notion that to be able to choose an alternative future and become an agent of it, an individual has to be exposed to it (Elder & Luscher, 1995).

Outputs

Operationally, the I SEE project produces five outputs that are briefly introduced in the following.

(1) *The I SEE start-up module* is a set of materials and a manual for teachers and students in upper secondary school (ages 16-19) for implementing an innovative teaching-learning sequence in the classroom and in out-of-school contexts. This

first teaching module, developed in close collaboration by all partners, dealt with the topic of climate change. The module consisted of a unified set of activities aimed at developing students' conceptual and epistemological knowledge and skills, future-scaffolding skills, and action competence and agency. Together these activities formed an intensive, week-long program of student group work, exercises, plenary lectures, a panel discussion and students' presentations. The module was implemented in an international summer school in June 2017 in Bologna, Italy, with a culturally diverse group of 24 Finnish, Icelandic and Italian upper secondary school students and their teachers.

(2) *The three implemented I SEE modules* follow the same aims, target group, structure and approaches as the first start-up module. The modules are based on the start-up module format and the results and experiences gained from its implementation. The three I SEE modules cover three cross-cutting and contemporary fields: climate change and carbon sequestration, artificial intelligence, and quantum computing and the development of ICT. The duration of the modules when implemented is 10-20 hours, just as for the start-up module. The modules contain lesson plans and materials for teachers' use as well as materials for students' guided and autonomous work. Instructions and tools for student evaluation are provided too. The final form of the three I SEE modules are refined through cross implementations and feedback in upper secondary schools in Finland, Iceland and Italy.

(3) *The I SEE module guide* provides a model and instructions for developing further I SEE modules. The guide is composed of a collection of design principles, commented examples and recommendations for implementations. Principles, examples and recommendations will characterize a module which is recognizable as an I SEE module. The guide is targeted both at teachers and researchers in science, technology and mathematics education. The guide has a function of being a dissemination tool because it is set up as an instrument specifically targeted at teachers and educators that is able to trace back to the realized project, the results of the implementation and the materials produced.

(4) *Case studies* aim to evaluate the most ambitious part of project: the potential of the I SEE modules to enhance students' capacity to aspire to and to imagine their future through inclusive activities in science education. In order to evaluate such a potential some studies on focal students or on focal collective dynamics will be carried out. The set of case studies will be developed to highlight:

- if and how the module impacts: i) students' imagination toward the future and ii) students' imagination about STEM careers;
- the progressive development of new STEM skills;
- the level and quality of inclusiveness created among students with different cultural backgrounds;
- the conditions that foster or hinder the effectiveness of the I SEE modules.

The case studies will be carried out through the analysis of both quantitative and qualitative data. Instruments and data sources include questionnaires, individual interviews, collective discussions, tutorials, audio/video records, specific grids and board diaries for observations. The specific tools for data collection will be chosen and designed to cover both individual development and collective dynamics. Data was collected during the implementation of the start-up module in 2017, and in 2018 more data will be collected when implementing the three modules. The analysis of the case studies translates into finding a way to not only explain what happens in the implementation of an I SEE module, but also what conditions are needed to overcome obstacles and maximize the probabilities of repeating successful experiences in different contexts.

(5) *Recommendations for crossing the barriers between schools and society* will be targeted at educational institutions (schools, science centres, educational centres, universities, research institutions, companies with an educational division) that are committed to addressing the skill-gap problem (EC/EACEA/Eurydice, 2012) by designing and offering stages and/or school-job market

collaborative experiences. The recommendations will be the result of a meta-analysis of the implementations carried out during the project and will be prepared in order to contribute to:
(i) making science teaching relevant from a scientific, professional, social and personal point of view and effective for supporting students to "see" their future and to take accountability for it;
(ii) enhancing the capacity of schools, universities, educational centres, NGOs and entrepreneurs to create local, regional and national forms of collaboration aimed at: (i) influencing the way science is taught in schools, (ii) fostering students' capacity to aspire and to imagine their future, and (iii) attracting, orienting and preparing students for future STEM careers, adhering to the values embedded in the EU's concept of Responsible Research and Innovation (European Commission, 2012).

Methodology

The project employs a comprehensive, holistic approach to address the complex issues in question. Improving science teaching is a wide and multifaceted process that has to take into account multiple dimensions: the disciplinary and epistemological ones, but also the identity, societal and vocational dimensions. Instead of a reductionist approach aimed at addressing one dimension at a time, we searched for a comprehensive central idea that could orient the production of multidimensional modules. It is the key-idea of future-scaffolding skills per se that is expected to enable science education to pursue a multi-dimensional goal: making science teaching relevant from a scientific, professional, social and personal point of view and effective for supporting diverse groups of students to imagine their futures and to exercise their agency.

As a methodological framework the I SEE project uses design-based research (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003; Plomp & Nieveen, 2013), involving an iterative process of designing, testing, and revising the modules, according to back and forth dynamics between theoretical hypotheses and empirical results. This process informs the methodology of the modules' production such that it will not follow a linear process (preparation, implementation and evaluation) but a back and forth, multiple round, dynamic process of reflection, revision and refinement. Unlike action-research, the design-based research methodology has an explicit theoretical orientation (Cobb et al., 2003; diSessa & Cobb, 2004) that enriches the goal to design and realize good practices with the purpose of explaining why a classroom practice is more or less successful. For this purpose, specific data are collected during the implementations and are analyzed through qualitative methods that include researchers' triangulation, practice reflexivity, as well as member-checking (with all the participants of the study, that is teachers, students, researchers) (Anfara, Brown & Mangione, 2002). These methods are particularly suitable to highlight not only what happens in a specific teaching/learning experience but also to provide an interpretation of why, when and how it happened (Plomp & Nieveen, 2013). The theoretical orientation of the design-based methods aims to maximize the materials' transferability in different contexts. Case studies will provide criteria to distinguish, in the complexity of a classroom environment, what is relevant from what can be considered negligible details.

The I SEE teaching and learning approach

Structural reference: A model for Socio-Scientific Issues

Our approach to futurize STEM education aims to incorporate future thinking to the societal, vocational and personal relevance of science, as well as its conceptual and epistemological value. The importance of exploiting the societal relevance of scientific contents in science teaching is, within STEM education, strongly stressed by the research on socio-scientific issues (SSI) and the teaching and learning approaches based on it. The I SEE approach draws from the ideas and structure of a recent conceptualization of the SSI approach by Sadler, Foulk and Friedrichsen (2017) (cfr. Figure 1).

Here we first present the key ideas of that model, and then introduce our model for futurizing science education.
First of all, the SSI approach is characterized by the choice of topics, socio-scientific issues that scholars think should be introduced and addressed in science teaching. SSIs are defined as controversial, ill-structured problems for which there is not a univocal, correct answer, and solutions are uncertain and complex. At a minimum, they have to incorporate two main elements: substantive connections to science ideas and principles, and social significance (Sadler, 2009). Examples of SSI include genetic engineering, climate change, animal testing for medical purposes, oil drilling in national parks, and "fat taxes" on unhealthy foods.
Secondly, the approach proposed by Sadler et al. (2017) to SSI defines the main lines of the teaching and learning model (SSI-TL model) in terms of the phases along which students are guided to work with the SSI. The SSI-TL model includes three phases (cfr. Figure 1): encountering the focal issue; engaging with science ideas, science practices and socio-scientific reasoning practices; and synthesizing key ideas and practices (Sadler et al., 2017). Throughout the teaching/learning process, students are encouraged to progressively develop their own positions on the SSI. To achieve this goal, they are guided to develop scientific knowledge as well as to consider social, political, economic, ethical, and moral aspects of the problem (Sadler, 2009). They should have opportunities to reflect on and refine their own beliefs and perspectives.
Empirical results have shown that SSI are effective contexts for the development of knowledge and processes contributing to scientific literacy, including evidence-based argumentation, consensus building, moral reasoning, and understanding and application of science content knowledge (Sadler, 2009; Zeidler & Sadler, 2011).

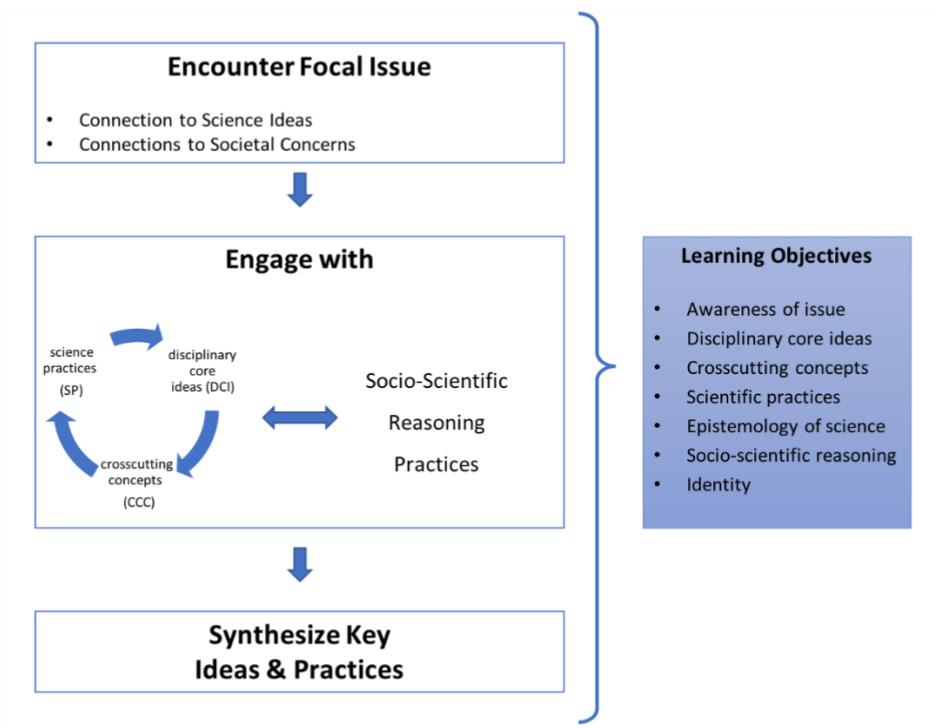

Figure 1. Graphic representation of the SSI Teaching and Learning model (Sadler et al., 2017)

The I SEE model to futurize STEM education

The I SEE model suggested here takes its point of departure from the SSI-TL model. Inspired by the SSI-TL model, our approach also suggests integrating science contents and their social relevance in STEM education. Moreover, our approach is also characterized by the choice of special topics and by a multiple phase teaching-learning model. Thereby, like in the SSI-TL model, the I SEE teaching model includes three main phases and identification of possible learning outcomes. The three main phases are (cfr. Figure 2):

1. encountering the focal issue;
2. engaging with the interaction between science ideas and future (main body of the module)
3. synthesizing the ideas and putting them into practice.

As far as the choice of topics is concerned, in our model focal scientific issues have to be *future-relevant*. This is distinct from the SSI-TL model in that topics not only include scientific contents and scientific practices (reasoning, arguing, explaining, etc.) but also are likely to be significant in students' future. They may, for example, represent a societal challenge or prospect that is controversial because of its implications for future societies, the environment, or working life. Such topics may be so-called *wicked problems* (Head, 2014; Turnpenny, 2012), which are not likely to be solved in the near future because of their complexity, or involve rapidly evolving technologies with great expectations. Examples of future-relevant STEM topics include climate change, artificial intelligence, nanoscience and nanomaterials, big data, and quantum computing. After encountering the focal issue, teaching activities are carried out to enable students to develop scientific and transversal future-scaffolding skills which allow them to engage with the future implications of the issue.

Despite the structural symmetry between the SSI-TL model and the I SEE model, there certainly are differences in the contents. Besides the distinctive focus on future in the choice of topics and of the activities, the I SEE model is independent of the U.S. curricula which are the main reference for SSI-TL model, as the emphasis on disciplinary core ideas, cross-cutting concepts, and scientific practices shows (Figure 1).

In the following sections we present each of the elements of the I SEE model (Figure 2) by discussing their essential features. We illustrate the ideas and discuss how they were operationalized when implementing the I SEE start-up module in the summer school in Bologna in June 2017.

Encountering the focal issue

The module begins with students encountering the focal issues (the upper block in Figure 2). This first experience aims to develop a preliminary level of awareness of the ways in which conceptual and epistemological scientific knowledge, the specific language, the methodological and the pedagogical approaches will interweave in the module. At this point, students are also introduced to social issues and problematic aspects of the topic. The focal issues are scrutinized in the context of post-normal science, recognizing the scientific uncertainties and the variety of stakeholders, interests and expertise influencing the problem, knowledge-making and decision processes (cf. Head, 2014; Turnpenny, 2012). Particularly, in the I SEE approach, the focal issues are characterized by the connections to STEM and future.

In the first start-up module implemented during the summer school of the project, two plenary lectures by Carlo Cacciamani (climatologist) and Peter Bishop (futurist) were expected to enable the students to build a global picture of, respectively, climate change and futures studies and begin to see the interconnection between science and future.

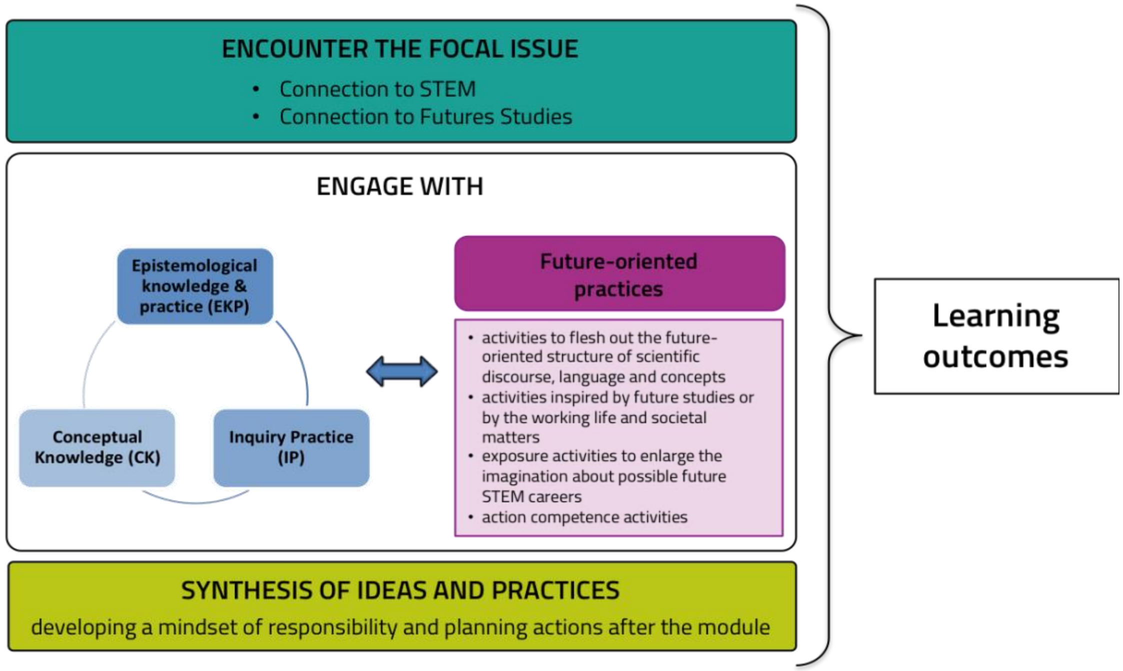

Figure 2. Main structure for I SEE model inspired by the SSI-TL model

In his lecture, Prof. Cacciamani stressed the implications of climate change and its societal dimension. In particular, he pointed out the main bodies of evidence that lead scientists to argue that we are facing significant changes in climate. The crucial point of the lecture was to give a big, complex picture from a multi-dimensional perspective and to introduce some fundamental ideas (like the notions of climate systems and feedback, the notion of scenario and IPCC graphs, the concepts of mitigation and adaptation, etc.) on which the conceptual and epistemological inquiry-oriented activities of the second phase are developed. Symmetrically, Prof. Bishop introduced fundamental concepts on which the future-oriented activities of the second phase are developed, in particular the distinction among possible, plausible and preferable futures (Voros, 2003) and the concept of *foresight* or *anticipation* that, unlike forecasting (which goes from the present to the future), starts by imagining possible futures and, through *back-casting* activities, returns to the present in order to design possible actions that can foster the achievement of a desirable scenario.

Engaging with the interaction between science ideas and future

The central block in Figure 2 presents the elements of the topic that students engage with in the module. The first part of the central block is the circle that links, in a circular dynamic, the three dimensions of science that are expected to give students a sense of disciplinary authenticity (Kapon, Laherto, Levrini, accepted):

i) *conceptual knowledge (CK)* – this dimension refers to the disciplinary content knowledge. CK is dealt with in the module according to the principles of educational reconstruction (Duit, 2007) implying that scientific contents are reconstructed for education through the analysis of scientific content structure, empirical research results on students' learning in the topic, as well as the main school-context constraints. In our case, special attention is also paid to the "critical details" needed to foster meaningful learning and consistence between local issues and the global rationale (Viennot, 2006);

ii) *epistemological knowledge & practice (EKP)* – this dimension refers to epistemic practice such as modelling, arguing, and explaining. This dimension has been proven to be fundamental for deep and meaningful learning (Chinn, 2018; Tasquier, Levrini & Dillon, 2016). Furthermore in many complex and future-relevant topics (like in the case of climate change) students have to be guided to grasp the shift in the epistemological paradigm (from the deterministic paradigm to the perspective of complex systems);
iii) *inquiry practice (IP)* – refers to inquiry skills such as posing questions, formulating hypotheses, designing inquiry, triggering peer-to-peer interaction, recognizing modelling as a process of isolating a particular phenomenon, and moving from models to experiments and vice versa.

In the I SEE summer school, the circular dynamics among the three dimensions were implemented through lab activities where students were guided to develop and practice scientific, conceptual and epistemological, and inquiry skills. Such skills included: modelling phenomena, testing hypotheses, making predictions, observing, planning, interpreting graphs and executing controlled experiments and measurements, analyzing data, communicating findings to peer groups, and forming arguments on the basis of empirical findings from the research evidence base.

Since the topic of the first I SEE module was climate change, the epistemic and inquiry skills were developed on the specific concepts and models that concern the greenhouse effect and that are needed to grasp its global implications. The following topics were covered: the process of interaction between matter and radiation; the energy balance mechanism explaining why changes in the composition of the atmosphere can cause changes to the Earth's surface temperature; the concept of anthropogenic greenhouse gases and their relation to global warming; the concepts of positive feedback needed to explain phenomena (e.g. melting of glaciers); and the space and time scales of climate modelling. Climate modelling implies a systemic, global approach that includes a new way of looking at possible future scenarios, from predictive to probabilistic and projective models. Active learning was stimulated through student-centered activities, group work, and the teacher's higher order type questions. Students were encouraged to consider their own role and significance to the phenomena, for example, in the activity where they calculated their own carbon footprints.

Future-oriented practices

The second part of the central block (Figure 2) concerns future-oriented practices.

The I SEE approach foresees at least four types of future-oriented practices that can be developed with the aim of turning knowledge into future-scaffolding skills and competences:

a) activities to flesh out the future-oriented structure of scientific discourse, language and concepts;
b) activities inspired by future studies or by the working life and societal matters;
c) exposure activities to enlarge the imagination about possible future STEM careers;
d) action competence activities.

The first type of activities (a) aims to highlight that the concept of future is intrinsic to the nature of science, being the goal of prediction at the core of scientific modelling. Even if it is very seldom emphasized in science teaching, future is absorbed and integrated into the epistemological structure of science and is closely linked to its models of causal explanation, which are gradually elaborated to make predictions (Barelli, 2017). Science has developed many temporal patterns and epistemological models of causal explanation, from linear up to probabilistic models elaborated within modern science (like for example the science of complex systems which are applicable to many STEM topics from the analysis of ecosystems, climatology and geophysics, to computer science). These fields can offer powerful concepts (like *space of possibilities, future scenarios, projection instead of deterministic prediction, uncertainty, sensitive dependence to initial condition, feedback and* *circular causality*) suitable for problematizing linear causality and that can be developed into skills for thinking and talking about the future (Barelli, Branchetti, Tasquier, Albertazzi & Levrini, 2018; Levrini et al., under review; Tasquier, Branchetti & Levrini, under review).

On the basis of these remarks, the I SEE approach includes the design of activities aimed to: i) flesh out the temporal patterns and the structures of causal reasoning elaborated within science; ii) turn basic concepts - like linear or circular causality, feedback, sensitive dependence on initial conditions - into skills to analyze texts where topics based on complex dynamics are described. In the case of the first I SEE module, in the summer school after an interactive lecture aimed to introduce the perspective of complexity and its basic concepts, the students were directly involved in the analysis of a text on biofuel. More specifically, they were asked both to point out the causal reasoning behind the argumentation, and the positive and negative feedback loops.

In our language, this type of activity is expected to develop "future-scaffolding scientific skills", that is skills that come from science and can support students to talk and to think about the future.

The second type of activities (b) are built to infuse science education with the perspective of Futures Studies (FS), which is a complex interdisciplinary field developed by a community of sociologists, philosophers, as well as academics in STEM, economics, politics and the entrepreneurial realm.

Drawing upon the science of complex systems, FS problematize the common belief that futures are only matters of making predictions, and stress them as ways to open up possibilities and solutions. One of the main ideas is that, since accurate predictions are not necessary and not possible (due to scientific constraints), it is socially, economically and personally important to develop skills for thinking about possibilities and ways to realize possible futures rather than predicting exactly what will happen. In this possibility perspective, the existence of a plurality of futures is crucial, and 'scenario' becomes a keyword. Scenario-building (or planning) is a tool for generating narratives about multiple futures, and has been used extensively in FS especially in the contexts of wicked problems such as climate change (Rickards et al., 2014).

Within the I SEE approach, we found particularly illuminating the distinction, made within FS, among possible, plausible, probable and preferable futures. The relationship among them is often represented with a 'futures cone' (Hancock & Bezold, 1994), elaborated by Voros (2003) (Figure 3).

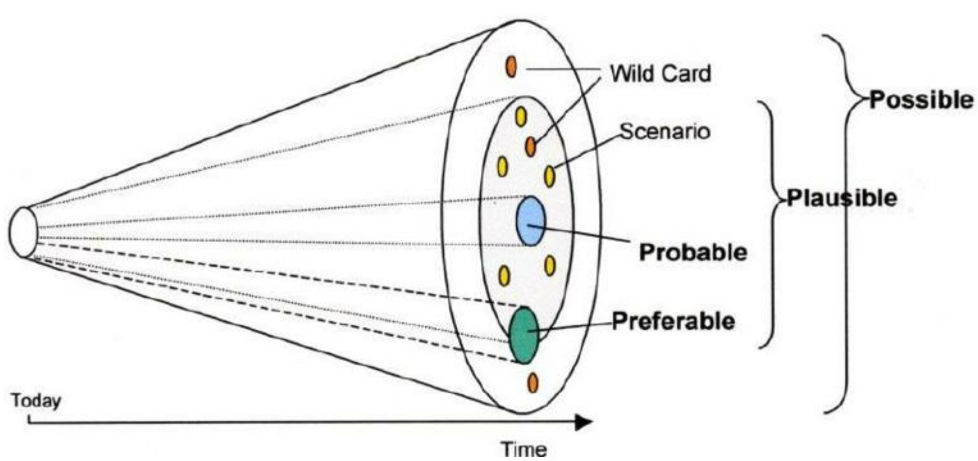

Figure 3. The futures cone by Voros (http://www.nesta.org.uk/blog/accuracy-and-ambition-why-do-we-try-predict-future) [Image credit: Ironing drone by Max Cougar Oswald & Nihir on the Noun Project via Creative Commons]

The I SEE approach gives a special emphasis to preferable (also called desirable) scenarios (Figure 3). While plausible and probable futures are largely concerned with informational or cognitive knowledge, preferable (or desirable) scenarios are concerned with people's wishes or aspirations. In other words, these futures are largely emotional and ethical rather than cognitive, and are thus more subjective than the other future types. To think in terms of preferable futures, students have to cope with their current values and desires, their identities, their competences and their cultural points of view, and to imagine a preferred scenario in which they would like to live. Within the summer school, the cone was introduced by Prof. Bishop in his plenary lecture and, during the core part of module, students were engaged in discussion and comparison of possible future scenarios for an imaginary city that depended on the different possible decisions of the city's mayor. The different possible decisions, as commonly happens, were not values-neutral and the students had to consider the complexity of the current situation where technological, social, and cultural progress have to cope with the big issue of climate change. The students were not only requested to point out the values that underpin the different models of development and different future scenarios, but also to discuss in groups about their "ideal city to live in 2030."

The exposure activities (c) are part of the approach with the aim of enlarging students' imagination about possible future STEM careers. Particularly, activities of this type are based on the idea that an individual, in order to be able to choose among alternative futures, has to be exposed to the sense of them. The exposure activities make STEM careers more attractive because, we conjecture, they will not only help students directly experience the acquisition of authentic professional competences but they will also support students to cope rationally, emotionally, creatively and responsively with their future. In the summer school the exposure activities consisted of a panel discussion with experts from various climate-related fields. The experts discussed their career paths, the choices they have made, their professional ambitions and other driving factors. After the panel discussion they stayed available for personal communication with the students.

Later in the summer school, the students carried out a final project in part of which they had to imagine themselves in a professional role in the future, which was meant to reinforce the imagining they had already begun in the exposure panel.

Finally, **action competence activities (d)** are thought 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. The action competence approach can be practiced in education by presenting students with the task to collectively decide on an issue, determine how to investigate it and address it. This affords multiple modes of participation to students and supports diverse student abilities and interests, particularly with respect to culturally-related differences. Such activities have the feature of activating a back-and-forth dynamic between present and future.

Action competence activities in the summer school included the final project described below in the following section.

Types b, c and d activities are expected to develop what we called future-scaffolding transversal skills, that is skills that do not have a scientific origin but that can be developed also within science classes with the aim of enabling students to project themselves into the future.

Synthesis of Ideas and Practices

The final phase of the module calls for students to synthesize ideas and practices they have encountered and engaged with throughout the whole pathway. After the experience of the previous activities, the students are ready for the more creative part of the module. First, working individually, they identify issues relevant to the topic and of interest to them. They then are grouped by common interests and guided through a process including analysis, evaluation, and planning around the issue. In this activity they take responsibility for their future and plan an action able to realize their desirable future. This is an important moment of synthesis and of cross-checking of values, since they have to choose what they can negotiate and what is not possible to be negotiated. This is also a moment in which, knowledge and practices acquired along the whole sequence begin to transform into skills in action. Students are challenged to find their active role in the complex interaction between individuals and nature.

In particular, the students in the summer school were required to project themselves into a desirable future in 2030. They were asked to plan and tell their success story – in the form of back-casting activity during their final presentations -- of how they managed to solve a critical problem (in this case about climate change) by using a leverage point to change the system. They were required to work together by grouping themselves according to shared values. Each student took a role in the change they had chosen for themselves, and the groups presented to their peers their future scenarios as a narrative of the past from the perspective of the year 2030 “in character” in their imagined roles.

This part of the model is very demanding on students’ imagination but also on their critical thinking and analytical skills. It serves as a challenging and empowering comprehensive activity as well as a springboard for other modules of other topics, or indeed many other kinds of learning activities that build on future imagination and systems thinking.

The synthesis of ideas is not only bound up to the end of the module but it is expected that the students, inspired by the I SEE experience, can continue developing a mindset of responsibility and planning actions after the module.

Learning outcomes

The I SEE teaching and learning approach aims at action competence (Mogensen & Schnack, 2010) and transformative learning (Dirkx, Mezirow & Cranton 2006) rather than plain cognitive learning outcomes. Since the project’s aims are to develop future-scaffolding skills and to foster students’ personal, societal and vocational agency and identity, the primary outcomes strived for are competences and the ability to put those competences into action. Transformative learning typically aims to develop reflective and critical thinking, holistic and systemic understanding, and transferring that understanding into action (Dirkx et al., 2006; Sterling, 2010). In the I SEE approach the development of such competence and agency entails learning aims at three levels, corresponding to the types of activities presented above: conceptual and epistemological knowledge, future-scaffolding skills, and action competence. In the following, some learning outcomes are specified for each level in regard to the climate change module.

First, learning outcomes related to *conceptual and epistemological knowledge* involved that students learn to model the greenhouse effect as a scientific phenomenon. To achieve this understanding, students learn or revise the physical concepts of, for example, radiation, heat, temperature, and interaction between matter and electromagnetic radiation. Besides the conceptual knowledge, the students should learn scientific epistemology and lab working skills, such as testing hypotheses, making predictions, observing, planning, and executing controlled experiments, and communicating findings to peer groups.

Learning outcomes concerning *future-scaffolding skills* involved that students get acquainted with basic concepts of science of complex systems (e.g. sensitive dependence on initial conditions, circular causality, positive and negative feedback loops) and become familiar with one of the main tools of the science of complex systems, the simulation. Students learned that approaching science phenomena that involve citizenship issues (e.g. climate change) implies a change in the epistemological way of looking at the phenomena itself: they learn, for example, that climate is a complex system and that the interpretation of phenomena related to it implies new types of explanation, modelling and argumentation. They also learn that approaching and tackling the effects of climate change implies a change in the ways we live in everyday life and we, collectively, make decisions. They become also personally committed to outline a desirable scenario and/or to point out a desirable objective to be reached in the future. Learning outcomes concerning *action competence* and agency include the ability to critique and revise their own future visions in the light of new knowledge and perspectives. Students become able to define, map and analyze a climate change problem of their choice, and to articulate a strategy to achieve a desirable solution for the problem, based on its systemic context.

Our experience and future directions

In this paper we have proposed a teaching and learning approach for futurizing science education, and described how that approach was used to develop the first I SEE module implemented in a summer school in June 2017 with students from three countries. In sum, the I SEE teaching and learning approach consists of three stages and learning outcomes connected to each of them: encountering the focal issue; engaging with the interaction between science ideas and future dimensions, and synthesizing the ideas and putting them into practice. The middle stage of the model is the main part, involving future-oriented practices that turn knowledge into future-scaffolding skills. We have suggested and described four kind of such future-oriented practices: a) activities to flesh out the future-oriented structure of scientific discourse, language and concepts; b) activities inspired by future studies or by the working life and societal matters; c) exposure activities to enlarge the imagination about possible future STEM careers; and d) action competence activities.

We conclude the paper with some experiences from the first implementation of the I SEE module. During the implementation in the summer school, many data were gathered. The data collection aimed to evaluate the potential of the modules to enhance students' capacity to aspire and to imagine their future through inclusive activities in science education. To cover both individual development and collective dynamics, we used a variety of data sources (e.g. focus groups, individual interviews, questionnaires, audio/video-recording of several discussions and activities).

The students' reactions that emerged from the focus groups and the individual interviews during the summer school imply that the activities of the module had a positive impact on students' perceptions of the future and sense of agency, on the personal experience of cultural diversities as well as on the capability to imagine future careers. To understand how the module brought about these outcomes, we have started a detailed analysis of students' discourse in the audio-recordings. We have already recognized systematic shifts and reactions within their discourse, and perceived some new vocabulary that became part of their way of thinking about the future. The results of this analysis will provide means to connect the outcomes to the future-scaffolding skills which were taught in the module. According to the preliminary analysis, many students abandoned their fear-inducing deterministic future views and started to talk about future scenarios, referring to a variety of possible, probable, plausible and desirable futures. They also showed vocabulary pertaining to complex systems and reasoned in terms of circular causality. Such findings from the discourse analysis help us understand which future-scaffolding skills were learned during the module and how they may contribute to students' thinking. The next steps of the analysis will be to match against the whole corpus of data in a systematic way in order to investigate the relationship between reactions and shifts in personal perspectives and the triggering of some particular skills.

As an overall reflection, it must be noticed that the group of students cannot be considered as representative. Indeed, these students were already somewhat interested in STEM and/or in climate change, and therefore no sweeping generalizations can be made about the influence of the module on students in general. In the further stages of the project, the developed approaches will be tested with larger and more diverse groups of students. Another challenge will be to match the modules with the curricular constraints of different countries. This requires a careful analysis to grasp the essence of the module. After that, we will render the materials and the activities adaptable to different contexts and practicable also by teachers who did not participate in the project.

Preliminary results of the first module implementation led us to reflect on the design process of our first I SEE module on climate change and to flesh out the essence of our approach and the skeleton of our model. Indeed, the trials currently ongoing of the new modules on quantum computing, carbon sequestration and artificial intelligence retain the structure and elements of the I SEE module as presented in this paper. They are being carried out in upper secondary schools in Italy, Finland and Iceland and will give valuable insight as to what the impacts of the I SEE model on teaching approaches and learning outcomes in science classes are and thus how widely applicable the model could be for accomplishing its goal of preparing learners for the uncertain futures. Together with the data from the summer school, the data from these trials will aid us in answering the question we posed to ourselves, how can we futurize science education?

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References

Anderson, B. (2010). Preemption, precaution, preparedness: Anticipatory action and future geographies. *Progress in Human Geography, 34,* 777–798.

Anfara Jr., V. A., Brown, K. M., & Mangione, T. L. (2002). Qualitative analysis on stage: Making the research process more public. *Educational researcher*, *31*(7), 28-38.

Barelli, E. (2017). Science of complex systems and future-scaffolding skills: a pilot study with secondary school students (Master dissertation in Physics, Alma Mater Studiorum - University of Bologna). Retrieved from AMS Laurea Institutional Theses Repository. (Accession No. 13644).

Barelli, E., Branchetti, L., Tasquier, G., Albertazzi, L., & Levrini, O. (2018). Science of complex systems and citizenship skills: A pilot study with adult citizens. *Eurasia Journal of Mathematics, Science & Technology Education*, *14*(4), 1533–1545.

Bauman, Z. (2001). *The individualized society*. Cambridge: Polity Press.

Bell, W. (2003). Foundations of futures studies I: History, purposes, knowledge. New Brunswick, NJ: Transaction Publishers. (Original work published 1997).

Benasayag, M., & Schmidt, G. (2006). *Les passions tristes: souffrance psychique et crise sociale.* Paris: La Découverte press.

Bergmann, W. (1992). The problem of time in sociology. An overview of the literature on the state of theory and research on the 'Sociology of Time', 1900-82, *Time & Society*, *1*(1): 81-134.

Börjeson, L., Hoöjer, M., Dreborg, K., Ekvall, T., & Finnveden, G. (2006). Scenario types and techniques: Towards a user's guide. *Futures*, *38*, 723-739.

Chinn, C. A. (2018). Modeling, explanation, argumentation, and conceptual change. In T. G. Amin & O. Levrini (Eds.), *Converging Perspectives on Conceptual Change: Mapping an Emerging Paradigm in the Learning Sciences* (206-226). London: Routledge.

Cobb, P., Confrey, J., diSessa, A. A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research, *Educational Researcher*, *32*(1), 9-13.

Dirkx, J. M., Mezirow, J., & Cranton, P. (2006). Musings and reflections on the meaning, context, and process of transformative learning. A dialogue between John M. Dirkx and Jack Mezirow. *Journal of Transformative Education*, *4*(2), 123–139.

diSessa, A. A., & Cobb, P. (2004). Ontological innovation and the role of theory in design experiments. *The Journal of the Learning Sciences*, *13*(1), 77-103.

Duit, R. (2007). Science education research internationally: Conceptions, research methods, domains of research. *Eurasia Journal of Mathematics, Science & Technology Education, 3*(1), 3-15.

EC/EACEA/Eurydice (2012). *Developing key competences at school in Europe: Challenges and opportunities for policy.* Eurydice Report. Luxembourg: Publications Office of the European Union.
Elder, G. H., & Luscher, K. (1995) (Eds.), *Examining lives in context: Perspectives on the ecology of human development* (pp. 101–139). Washington, DC: American Psychological Association.
EP EB395 (2014). Flash Eurobarometer of the European Parliament: European youth in 2014. Analytical synthesis. Brussels: Public Opinion Monitoring Unit of the Directorate-General for Communication.
Eurobarometer (2015). Public opinion on future innovations, science and technology. *National report Italy, Eurobarometer Qualitative Study*, June 2015.
European Commission (2012). Responsible research and innovation – Europe's ability to respond to societal challenges. Luxembourg: Publications Office of the European Union.Giddens, A. (1991). *Modernity and self-identity: Self and society in the late Modern Age*. Stanford: Stanford University Press.
Hancock, T., & Bezold, C. (1994). Possible futures, preferable futures. *Healthcare Forum Journal*, *37*(2), 23–29.
Head, B. W. (2014). Evidence, uncertainty, and wicked problems in climate change decision making in Australia. *Environment and Planning C: Government and Policy, 32*, 663–679.
Hicks, D. (2006) *Lessons for the future: The missing dimension in education*. Victoria, BC: Trafford.
Jensen, B. B., & Schnack, K. (1997). The action competence approach in environmental education. *Environmental Education Research*, *3*(2), 163-178.
Kapon, S., Laherto, A., & Levrini, O. (accepted). Disciplinary authenticity and personal relevance in school science. To be published on *Science Education*.
Levrini, O., Tasquier, G., & Branchetti, L. (under review). Developing future-scaffolding skills through science education. Submitted to *International Journal of Science Education.*
Lotz-Sisitka, H., Wals, A. E., Kronlid, D., & McGarry, D. (2015). Transformative, transgressive social learning: Rethinking higher education pedagogy in times of systemic global dysfunction. Current Opinion in Environmental Sustainability, *16*, 73-80.
Meadows, D. H., Meadows, D. L., Randers, J., Behrens, III, W. W. (1972). The limits to growth; A report for the Club of Rome's project on the predicament of mankind. New York: Universe Books. ISBN 0876631650. Retrieved 26 November 2017.
Mogensen, F., & Schnack, K. (2010). The action competence approach and the 'new' discourses of education for sustainable development, competence and quality criteria. *Environmental Education Research*, *16*(1), 59-74.
Paige, K., & Lloyd, D. (2016). Use of future scenarios as a pedagogical approach for science teacher education. *Research in Science Education,* 1-23.
Plomp, T., & Nieveen, N. (Eds.) (2013). *Educational design research*. Enschede: SLO.
Rickards, L., Ison, R., Fünfgeld, H., & Wiseman, J. (2014). Opening and closing the future: Climate change, adaptation, and scenario planning. *Environment and Planning C: Government and Policy, 32*(4), 587-602.
Rosa, H. (2013). *Beschleunigung und Entfremdung - Entwurf einer kritischen Theorie spätmoderner Zeitlichkeit, (*Eng. Trans: *Acceleration and Alienation - Towards a Critical Theory of Late-Modern Temporality*, 2015). Berlin: Suhrkamp Verlag AG.
Roth, W.-M., & Lee, S. (2004). Science education as/for participation in the community. *Science Education*, *88*, 263-291.
Sadler, T. D. (2009). Situated learning in science education: Socio-scientific issues as contexts for practice. *Studies in Science Education, 45*(1), 1-42.
Sadler, T. D., Foulk, J. A, & Friedrichsen, P. J. (2017). Evolution of a model for socio-scientific issue teaching and learning. *International Journal of Education in Mathematics, Science and Technology,* *5*(2), 75-87. DOI:10.18404/ijemst.55999.
Sterling, S. (2010). Learning for resilience, or the resilient learner? Towards a necessary

reconciliation in a paradigm of sustainable education. *Environmental Education Research 16*(5–6), 511–528.
Stuckey, M., Hofstein, A., Mamlok-Naaman, R., & Eilks, I. (2013). The meaning of 'relevance' in science education and its implications for the science curriculum. *Studies in Science Education, 49*(1), 1-34.
Tasquier, G., Branchetti, L., & Levrini, O. (in preparation). Developing future-scaffolding skills: A study on a teaching/learning module about climate change and project design. To be published in the ESERA Science Education Research Series book of selected papers from ESERA 2017 conference.
Tasquier, G., Levrini, O., & Dillon, J. (2016). Exploring students' epistemological knowledge of models and modelling in science: Results from a teaching/learning experience on climate change. *International Journal of Science Education, 38*(4), 539-563.
Turnpenny, J. R. (2012). Lessons from post-normal science for climate science-sceptic debates. *Wiley Interdisciplinary Reviews: Climate Change*, *3*(5), 397–407.
Tytler, R. (2014). Attitudes, identity and aspirations towards science. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of Research on Science Education* (82-103). New York: Routledge.
Viennot, L. (2006). Teaching rituals and students' intellectual satisfaction. *Physics Education*, *41*, 400-408.
Voros, J. (2003). A generic foresight process framework. *Foresight*, *5*(3), 10-21.
Zeidler, D. L., & Sadler, D. L. (2011). An inclusive view of scientific literacy: Core issues and future directions of socioscientific reasoning. In C. Linder, L. Ostman, D. A. Roberts, P. Wickman, G. Erickson, & A. MacKinnon (Eds.), *Promoting scientific literacy: Science education research in transaction* (176–192). New York: Routledge/Taylor & Francis Group.