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O3 -I SEE module guide

I SEE

It's your time to imagine the futures

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Chapter 1

The I SEE project and instructions to use the guide

The project I SEE (September 2016- August 2019) 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 project had its origin in the phenomena observed during science classes at upper secondary school: the difficulty of the younger generations to cope with an unpredictable future and with the challenges of this global, fragile and changing world. Sociologists are studying these difficulties and have highlighted an aspect that is as obvious as difficult to deal with. We are in a frantic present, completely oriented toward seizing the moment, sniffing out every opportunity, and keeping open all possible scenarios (Leccardi, 2009); we are in the presence of a very strong technological acceleration (*"Society of acceleration" Rosa, 2013*) and schools and cultural institutions struggle to rethink knowledge and turn it into effective keys to reading what is happening and building a new vision of the future. It is in this gap that lies the problem of the lack of sense and relevance that young people denounce in talking about school knowledge, as well as the problem of their fragility, anxiety and, in many cases, new forms of rejection of the school and the knowledge it offers.

The question we asked ourselves was*: How can science teaching contribute to developing competencies for managing, rationally and emotionally, uncertainty towards the future and to push imagination forwards?*

The goal of the project is to design and implement innovative approaches and teaching modules on future-oriented scientific issues to foster students' capacities to imagine the future and aspire to STEM careers. The I SEE partnership developed a start-up module on climate change, and three more mature modules on Artificial Intelligence, Carbon Sequestration and Quantum Computing.

The modules are targeted to 16-19 years old students and do not only aim to develop professional skills but also to foster the development of students' identities as capable persons and citizens in a global, fragile and changing world.

To this end, the project focuses of specific skills that should be developed through science education in school and out-of-school contexts and that we call ***future-scaffolding skills***.

These skills have the feature to render science learning relevant – personally, socially, professionally and scientifically – and refer to the ability to construct visions of the future that empower action in the present with an eye on the horizon.

At the beginning of the project the concept of future-scaffolding skills was an inspiring and orienting idea that we referred to skills like scenario thinking, systems thinking, thinking beyond the realm of possibilities, action competence, managing uncertainty and complexity, and creative thinking. At the end of the project, we can provide an operational list of skills that the I SEE modules contribute to developing and that can be monitored through appropriate evaluation tools.

In this guide we describe the design principles that characterize the I SEE modules (Chapter 2), advice to implement them or to design new modules (Chapter 3), tools to monitor the implementations (Chapter 4) and a list of references to deepen aspects of the approach (Chapter 5).

The guide is designed to give a concrete overview of the I SEE modules so as to help a teacher or a curriculum designer to recognize and interpret the specific choices we made in the design of the modules and in their multiple implementations. A more theoretical research-based description of the approach can be found in Branchetti, Cutler, Laherto, Palmgren, Tasquier & Wilson, 2018.

Before entering the various chapters, we wish to provide an overview about the reactions we observed from the students to the I SEE modules. We hope they can work as a guiding light throughout the navigation of the guide.

Since the first implementation of the start-up module, we could perceive that the activities of the module had a positive impact on students' perceptions of the future and sense of agency, as well as on their capability to imagine future careers. We have recognized systematical shifts and reactions within their discourses and perceived some new vocabulary that was becoming part of their way of thinking about future.

A more systematic analysis matching against the whole corpus of data has provided means to connect the outcomes to the future-scaffolding skills which students were able to develop through the module. According to our analysis, many students described their experience as a process that led them to *widen* their views about the future and to feel the future more *approachable*.

In particular, in students' discourse, difference nuances of *widening* could be recognized. Widening: in the range and depth of knowledge on future thinking; in the range of new ways of addressing and looking at the future-oriented scientific issues (FoSI); in the range of possible roles of non-expert stakeholders (e.g. citizens, policy-makers) for addressing the FoSI; in the range of possible roles of expert stakeholders (STEM researchers and other experts in the field) for addressing and developing the FoSI; in the range of possible actions, strategies and concrete solutions that can be undertaken to address the FoSI.

As for the feeling of future *approaching*, students said that, after the module, they perceived the future: closer to their imagination, i.e. from far and unimaginable, it became thinkable to them; closer to their present reality, i.e. it became approachable through concrete actions that can be undertaken in the present; closer to their 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.

The analysis also led us to recognize development of *future-scaffolding skills* that we organized in two macro-categories (see Table 1): systemic-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 trivialising the relations between local details and global views, the relations between past-present-future, and the role of individual and collective actions.

Not all the students developed these skills, but the analytic process allowed us to recognize them as future-scaffolding skills: skills to provide a thinking scaffolding from which the future can be seen and used to orient actions in the present.

The students become able to:	
St1	distinguish between disciplinary details and the comprehensive picture of the FoSI
St2	unpack the FoSI into simpler, addressable parts
St3	recognize causal relationships
St4	recognize logical relationships (e.g. distinguish between problems, objectives and solutions or between pros and cons)
Dyn1	move from thinking locally to thinking globally (and vice versa)
Dyn2	move from thinking at the present to thinking at the future (and vice versa)
Dyn3	move from thinking at the individual to thinking at the societal community
Dyn4	think creatively for imagining new possibilities and concrete actions
Dyn5	balance the need of desiring and the necessity of keeping feet on the ground
Dyn6	think in a multidisciplinary way, breaking down the barriers among disciplines

Table 1. Future-scaffolding skills

Chapter 2

I SEE teaching and learning approach: the design principles

2.1 The choice of topics

An I SEE module is, first of all, characterized by the topic chosen: the topic of an I SEE module has to be *scientific, future-relevant* but also *of genuine interest* to students.

The topics 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 – which are not likely to be solved in the near future because of their complexity – or involve rapidly evolving technologies with great expectations.

Furthermore, the topics have to be complex and multidimensional enough to be relevant from the scientific, personal, societal and vocational points of view. This implies that such topics have the potential to be attractive for the students.

Design principle
The topic of an I SEE module has to refer to scientific contents and scientific practices (reasoning, arguing, explaining etc.) and that is significant for future. More specifically, the topic should be: • ***future-oriented*** in the sense that it touches aspects that will influence our society in the near to mid-term future; • ***complex*** in the sense of multi-disciplinary and multi-dimensional; it has to involve scientific, societal, economic, political, behavioural, identity dimensions; • ***relevant*** in scientific, personal, societal, vocational ways; • ***glocal*** in the sense that it addresses a global issue but which also has local ramifications.

In the first start-up module, implemented during the summer school in Bologna in June 2017, the topic was *climate change.* Further STEM topics that could be object of an I SEE module include: Artificial Intelligence, nanoscience and nanomaterials, big data, quantum computing… The project implies that the topics be advanced and cutting-edge but, we guess, it is possible to extend the methods and the approach to curricular topics.

2.2 The module structure

An I SEE module is structured into several teaching-learning phases, each with specific features and activities; the activities are carried out to enable students to develop future-scaffolding skills which allow them to engage with the future implications of the issue.

An overview picture of the structure is represented in figure below.

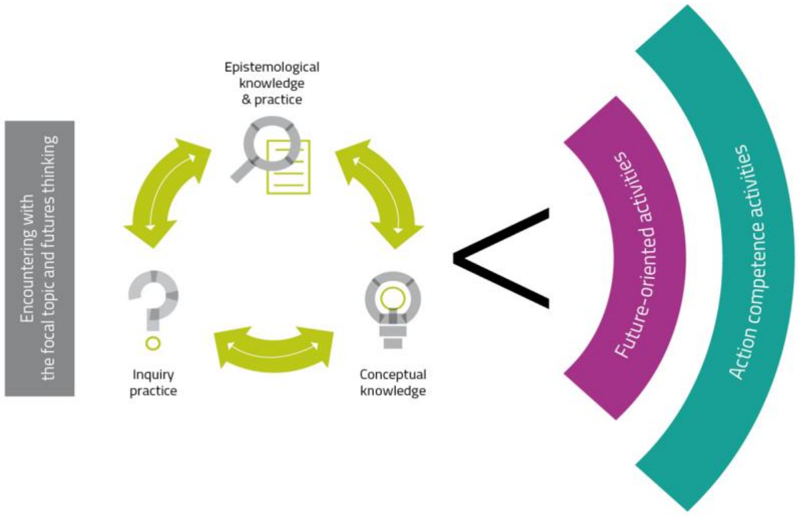


Figure 1. Main structure for I SEE model

The different teaching-learning phases are represented in the figure by different colours. They are called: *encountering the focal issue; engaging with the interaction between science ideas and future; bridge activities; future-oriented activities; action competence activities.*

Below, after a brief description of each phase, we highlight the principles to design the corresponding activities. Finally, to exemplify how you can make operational the design principles, for each phase, we refer to the first I SEE module designed on Climate Change and implemented in the summer school (June 2017).

Encountering the focal issue

The module begins with students encountering the focal issues (the left section in Figure 1). 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 some social issues and problematic aspects of the topic. Particularly, the focal issues are characterized by the connections to STEM and future.

Design principle
In the design of the opening activities, lectures or teamwork have to guide the students to encounter both the scientific topic and its multiple dimensions, and the issues of future and STEM carriers. Take care that the activities have to: a) open up the specific language, the conceptual and epistemological dimensions, as well as the social, political, ethical, economic issues connected to the topic, and b) introduce future thinking and the futures perspective as a horizon of the whole module.

In the climate change module, two plenary lectures by a climatologist (C. Cacciamani) and a futurist (P. Bishop) 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.

Engaging with the interaction between science ideas and future

This phase of the module (central section in Figure 1) presents the fundamental elements of the topic that students engage with. It represents a 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, 2018):

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.

Design principle
In the design of the activities related to the scientific topics, three dimensions of science have to be taken into account: • ***CK****:* disciplinary content knowledge; • ***EKP****:* epistemic practice such as modelling phenomena, arguing and explaining; • ***IP****:* 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. The EKP and IP dimensions are very important because they can pave the way to connect scientific contents to the next phases, related to future: modelling, inquiry, arguing are indeed practices that can be exploited and developed as future scaffolding skills.

In the climate change module, 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 with measurements, analysing data, communicating findings to peer groups, and forming arguments on the basis of empirical findings from the research evidence base.

Specifically, the epistemic and inquiry skills were developed from the 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.

Bridge activities

This phase of the module (the "less then symbol" in Figure 1) concerns the so-called bridge activities. These activities connect scientific, conceptual and epistemological knowledge and practice such as inquiry skills with the issue of the future.

Design principle
In the design of the bridge activities, special attention has to be posed to exploit the connection between the scientific topic, developed in the previous activities, and the rest of the module. This is a critical and delicate moment for the design, since it implies a deep analysis of the scientific topic so as to flesh out its potential to develop, from science, future-scaffolding skills. They can refer to the causal models implied in scientific topic, system thinking, or its social, political, ethical, economic implications. The design of the bridge activities has to be carried out together with the previous and the following ones.

Within the summer school, the students were directly involved in the analysis of a complex citizenship context of urban planning taking into account the social, political, economic implications that their decisions have.

Future-oriented activities

This phase of the module (the first part of the section on the right represented by arcs in Figure 1) concerns future-oriented activities.

The I SEE approach foresees at least three 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;

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 emphasised 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 (Levrini et al., under review). Science has developed many temporal patterns and epistemological models of causal explanation, from linear up to probabilistic models elaborated within modern science (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 *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.

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.

Within the I SEE approach, we found particularly illuminating the distinction, made within FS, among possible, plausible, probable and desirable futures. The relationship among them is often represented with a 'futures cone' (Hancock & Bezold, 1994), elaborated by Voros (2003) and now revised by us- (Figure 2).

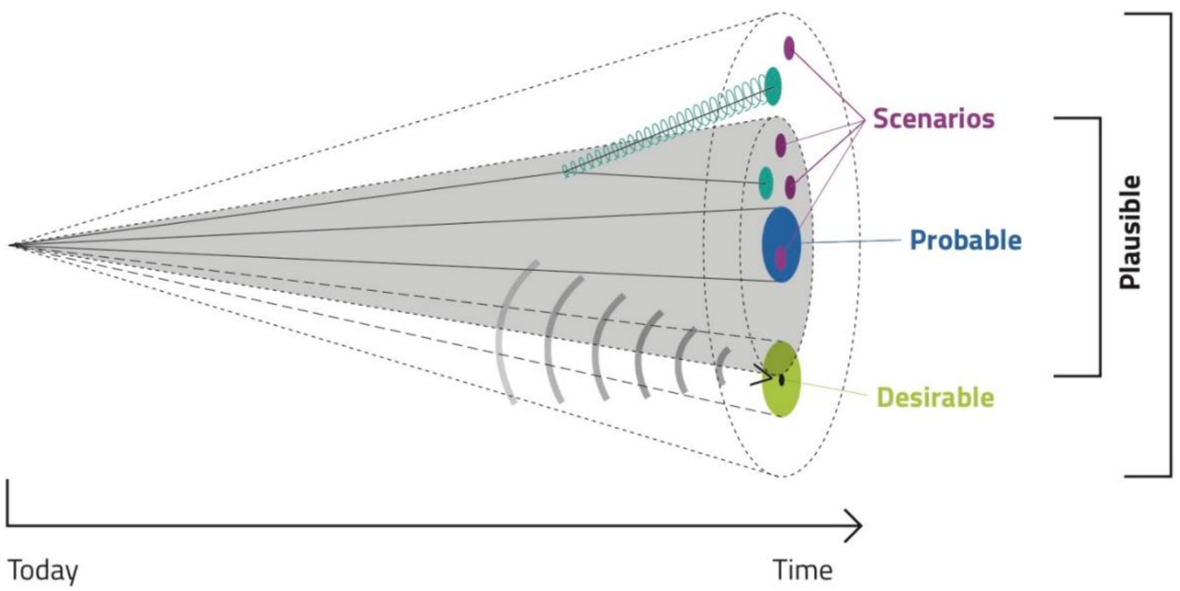


Figure 2. The futures cone Voros (revised version)

The I SEE approach gives a special emphasis to preferable (also called desirable) scenarios (Figure 2). 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.

The third type of 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.

Design principle

In the design of future-oriented activities, special attention has to be posed to turn knowledge into *future-scaffolding skills* and competences: skills that have the feature to render science learning relevant – personally, socially, professionally and scientifically – and refer to the ability to construct visions of the future that empower action in the present with an eye on the horizon (see chapter 1).

In the design of the activities, at least these three types of future-oriented practices have to be taken into account:

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

Especially for the first type of practices, take care that students have to be stimulated to: a) flesh out the temporal patterns and the structures of causal reasoning elaborated within science; b) turn basic concepts - like linear or circular causality, feedback, sensitive dependence on initial conditions - into skills to analyse texts where topics based on complex dynamics are described.

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 **(first type of activities - a).** As for **the second type of activities (b**), 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 third type of activities (c)** consisted of exposure activities carried out through 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.

Action competence activities

This phase of the module (the second part of the section on the right represented by arcs in Figure 1) concerns action competence activities. These activities 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.

This 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.

This part of the module 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.

Design principle
In the design of these activities, special attention has to be posed to activate a return dynamic between present and future. Take care to encourage students to become aware of the plurality of perspectives at stake in decision-making processes, and to broaden their ethical consideration in making intentional decisions and taking deliberate actions. Take also care to present students with the task of deciding collectively on an issue, determining how to investigate and address it. This offers students multiple ways of participating and supports different skills and motivations of the students, particularly with regard to cultural differences.

In the summer school, the students were required to project themselves into a desirable future in 2030. They were asked to plan and tell their success story 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.

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 with 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 as part of the climate change module. 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 become confident with 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 the 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 different 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 analyse 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.

Chapter 3

Implementing the modules in real classes

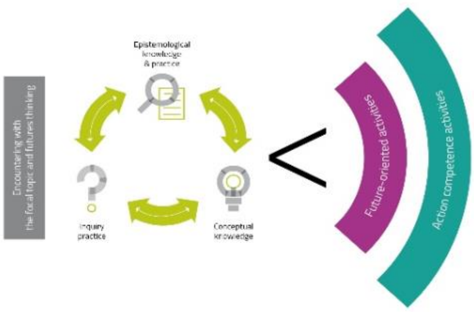
In this chapter we provide concrete examples of how the design principles, highlighted in chapter 2, can be recognized in our modules and can be used to design and implement new modules. The examples are taken from the activities developed in the modules on Carbon Sequestration, Artificial Intelligence and Quantum Computing; these modules have been carried out in secondary schools in Iceland, Italy and Finland and cross-implemented.

The complete modules can be downloaded at the following address: https://iseeproject.eu/category/teaching/

All the activities of each module are described in detail (their goals, their articulation in activities, the materials, and methods etc. …) following a specific template that is described in the following paragraph.

3.1 The design structure (template) of the activities

The following template has been used to design and present all the activities of the I SEE modules. Thus, it can be used to consult and compare the activities already designed, but also as a guide to design new I SEE activities.

Position in the module	The activity is, first of all, located within the module.  The position is then explained through a brief introduction to the activity.
Goals	The goals of the activity are articulated in conceptual, epistemological and social/emotional goals.
Time required	Time required for each phase of the activity is explicitly written so as to give concrete information/decide about the level of details and the degree of depth the activity is supposed to reach.
Materials/ Teaching Methods	In this field, a synthetic description of the physical support of the materials (slides, videos, video-recorded lecture, worksheets, tutorials, texts, interview questionnaire…) and/or a description of the conceptual flow of the materials contents are reported. The description of the materials can include the requests that the teacher does to the students
Tips for teachers from previous classroom	This field include tips, comments, remarks useful for teachers. Two types of annotations for the teachers can be identified: • tips, comments, remarks coming from the implementations and that are considered useful to conduct activities and to find strategies appropriate to the classroom context;

experiences	• tips, comments, remarks coming from the iterative process of design and revision and that show how aspects have been modified in light of students' reaction. In other words, these comments illustrate how the final activity structure was determined.

3.2 Operational recommendations to implement/design the activities

3.2.1 The goals

The goals have been/should be written to be as much alive and inspirational as possible, but also specific enough to make it clear how they are linked with the activity; the goals are student-centered so their formulation has to show what the students are expected to learn and not what the teacher is expected to teach.

The goals are articulated as *conceptual*, *epistemological* and *social/emotional*

Conceptual goals

Conceptual goals refer to	• scientific concepts; • concepts related to future studies (for example the concepts of scenario, futures cone …); • methodological issues (for example the concepts of the causal map, action competence…); • thinking processes related to the acquisition of conceptual knowledge or skills.
Examples of how to formulate the goals	• to understand the concept of… • to comprehend … • to get acquainted with… • to learn to apply the concept… • ……..

Epistemological goals

These goals are maybe the most complicated, but they are particularly relevant since they are the links between science and future.

Epistemological goals refer to	• scientific epistemic practices such as modelling, explaining, argumentation …, as they are accepted as characterizing the nature of science. • meta-cognitive skills, that is to recognize that some features of conceptual or procedural knowledge characterize in fact scientific knowledge or practices.
Examples of how to formulate the goals	• to comprehend … • to get acquainted with the idea or the concept … • to compare the XXX model with … • to recognize the XXX model of causal explanation behind XXX … • to move from a deterministic view to explanation to … • …

Social/emotional goals

Social/emotional goals refer to	• the ways the activity impacts on learners' personal development; • students' social and emotional learning as individuals and as individuals as part of society.
Examples of how to formulate the goals	• to get involved personally in collective discussion… • to raise awareness of the values implied … • to learn to share and empathize with different points of view • to learn to cope rationally, emotionally, creatively and responsively with their future • to enlarge the imagination about possible future STEM careers.

The meta-cognition level can easily overlap with the conceptual dimension. The distinction depends on the teacher, on how she/he stresses to what extent a conceptual aspect makes that piece of knowledge or process a scientific one (to what extent a teacher points out the epistemological dimension of knowledge).

3.2.2 Activities of encountering with the focal topic and futures thinking

According to the design principle, these activities have to guide the students to encounter both the scientific topic and its multiple dimensions (conceptual, epistemological, social, political, ethical, economic…), and the issues of future and STEM carriers.

Operational recommendation: when implementing or designing your activities, keep in mind that the encountering activities have to be effective to activate *curiosity* and provide *overarching ideas* that can guide and support the navigation throughout the module.

Examples from….

Artificial Intelligence module

This phase of the module has been developed in two activities.

a) "Two overview lectures" activity

This activity concerns two lectures aimed to open up to conceptual and epistemological knowledge that underpin both the scientific topic (AI) and the futures thinking (the perspective of complexity).

In particular:

- the first lecture offers an overview of the development of Artificial Intelligence in the last years, by stressing the idea that a paradigm shift occurred in the mid-90s, when neural networks and machine learning became a widespread approach to AI. In this lecture the key concepts of AI are introduced so as to pave the way to their future analysis and development in all the activities of CK-EKP-IP section;
- the second lecture has been realised to open to the perspective of complexity. The concepts introduced in this second lecture (non-linearity, sensible dependence of initial conditions, feedbacks, levels of descriptions, emergent properties…) are supposed to frame the whole module and, in particular, the future-oriented activities (activities 7-8 -9-10).

b) "Where can Artificial Intelligence (AI) be encountered today?"

The activity guides the students to build an overall picture of where Artificial Intelligence can be met nowadays and introduces the different dimensions (political, social, economic, professional, ethical …) that are involved in the applications of Artificial Intelligence. Concretely, in team-working, students are guided to analyse six different cards – each referring to a different field of AI applications. The students are guided through questions to select the application they find most interesting and explore their implications on future professions. The questions have been formulated to foster personal involvement, the activation of personal interests, and to learn to share different points of view and to mediate between them.

Quantum Computing module

This phase of the module has been developed in two activities.

a) "The Future Quiz"

This activity probes the assumptions the students have about the future. It encourages them to question their initial way of thinking and to look at the future more open-mindedly.

Students take the future quiz that contains questions such as:

Can we know about the future?
Is there only one future or multiple futures?
How far to the future can we make predictions so that they are still useful?
Is the future predefined?
What affects the future most?
What are the most important reasons for wrong predictions?
Is it useful to tell stories about unlikely but possible futures?

After taking the quiz, the questions and the students' answers are discussed together. The quiz and discussions around it build the ground for the subsequent future-oriented activities.

b) "The history, present and future of ICT"

The lecture introduces the evolution of ICT and computing power throughout recent history and speculates their possible future development. It guides students to contemplate their own attitude towards technology and shows alternative ways of seeing it. The activity provides a good opportunity to discuss the role of technology in changing society and working life. Quantum computing is introduced as a possible future step in the progression of ICT and computing power.

Carbon Sequestration module

This phase of the module has been developed in one activity.

a) "Introduction to climate change and carbon sequestration"

This lecture introduces students to the most essential concepts necessary to understand climate change and carbon sequestration. Topics covered include: carbon chemistry, the greenhouse effect, feedback loops, organic and inorganic carbon cycles and carbon sequestration through mineralization. At the end of the lecture, students will grasp the big picture of why and how climate change and carbon sequestration work and why they are so important to understand and be able to act on for the future.

3.2.3 Activities about conceptual knowledge (CK); epistemological knowledge & practice (EKP); inquiry practice (IP)

According to the *design principle,* these activities have to be related to the disciplinary concepts *(CK)* together with the development of epistemic and inquiry practice (EKP) and *(IP).*

Operational recommendations: when designing your activities, keep in mind that both the conceptual and the epistemological goals are important. Thanks to these activities the students can be guided to grasp the contribution that science can provide to develop future-scaffolding skills: the forms of reasoning of scientific discourse and, in particular, the structures of casual reasoning that characterize the shift from the deterministic paradigm to the perspective of complex systems. We deeply recommend to stimulate students through student-centered activities, group work, and the teacher's higher order type questions.

Examples from…

Artificial Intelligence module

This phase of the module has been developed in six activities.

The activities guide the students to grasp the paradigm shift in programming Artificial Intelligence that occurred with machine learning: unlike the traditional forms of programming, in machine learning a machine learns to solve a problem or to perform a task without knowing the strategy (an explicit knowledge base or the sequences of actions to be performed). It learns by "looking" at examples taken from appropriate databases.

In order to reach these goals, a problem has been chosen – winning the TIC-TAC-TOE game – and students are guided to compare how the different programming approaches would address the problem. In particular, a set of six activities was designed: three activities (*Activities 3-4-5)* introduce three different approaches (imperative, logical-declarative, machine learning) and three activities (*Activities 3bis – 4bis – 5bis)* show how a computer can be programmed to play "TIC-TAC-TOE" following the various approaches.

The examples are programs in typical language of each approach – respectively Python for imperative programming; Prolog for declarative programming; MATLAB for Machine Learning, but students do not need to know the languages. The activities are designed to stress the logics and not the technicalities.

The six activities are designed to foster a circular dynamics to connect conceptual and epistemological knowledge and epistemic practices. In particular, their comparison should allow a teacher to stress:

- the kind of structure of casual reasoning (linear or not) and of paradigm of prediction (deterministic or not) underpin each approach and what features characterize each form of reasoning;
- the point of view of the complexity that characterises the approach based on examples with respect to the "classical" ones.

Quantum Computing module

This phase of the module has been developed in seven activities.

In these activities, by studying different numeral systems, logical operations, algorithms and hardware components students prepare themselves to make the fundamental shift in computing paradigm and replace bits with qubits. Learning the quantum properties using the "spin first" approach paves the way for understanding quantum algorithms and thereby the superior computing power and future opportunities offered by quantum computers.

In the first part of the module, students learn that classical computers use the binary numeral system to present information. They learn to perform basic algebraic operations on bits and then proceed to more complicated operations. They are also introduced to the idea of an algorithm as a recipe to solve problems.

In the second part of the module, the core concepts of quantum mechanics and quantum computing are introduced in an activity described more thoroughly below. The limits of classical computing in simulating complex systems is shown and possibilities offered by quantum computers are introduced. Students learn to perform the basic operations on qubits, and the module culminates in an introduction to the simplest real quantum algorithm, Deutsch's algorithm.

"Introduction to Quantum Mechanics"

This activity introduces the core concepts of quantum mechanics and quantum computing. The introduction is done using a simplistic description of synthetic experiments (the Stern-Gerlach experiment), and the aim is to make quantum mechanics as approachable as possible without losing scientific accuracy. Students are encouraged to abandon the classical way of thinking and step from causal logic to making probabilistic predictions.

The introduction to quantum mechanics begins by noting that an electron has certain binary properties (spin). Using the Stern-Gerlach experiment, it is shown how these binary properties manifest themselves in measurements, and the concept of superposition and quantum mechanical probability interpretation are introduced. Students learn also to express simple quantum mechanical systems mathematically using the so-called Dirac notation.

We developed the activity so that it fosters conceptual and epistemological knowledge that Is

- to understand the concepts of a vector and superposition of vectors
- to become familiar with the concept of a state vector
- to become familiar with the ideas of the probability interpretation and normalization of a state vector
- to discuss and cross the epistemological barriers between classical and quantum realms

to realize that physics problems do not always have a definite solution.

Carbon Sequestration module

This phase of the module has been developed in two activities.

These two activities bring students into the role of the scientist calculating amounts of carbon dioxide it is possible to sequester through two methods: reforestation and mineralization.

In the activity "carbon binding in trees" students get the opportunity to learn hands-on in the field how to measure and calculate the carbon content of trees. In the classroom, they relate these measurements and calculations to known amounts of carbon emissions.

The main learning points of the activity include:

- how to find out the height of a tree using the Pythagorean theorem
- how to use tools to measure the diameter of a tree trunk
- how to calculate the standing mass of carbon contained in a sample plot of forest from the biomass of the sample and extrapolate that to a larger area of forest
- to relate the standing carbon mass to the amount of carbon binding per year for the forest

- to compare the amount of sequestration to emissions based on various CO_2-emitting activities

In the activity "carbon sequestration through mineralization," students will gain competence in calculating theoretical quantities of carbon that can be sequestered through mineralization, based on real-world, cutting-edge research. Students should have already encountered the focal issue of climate change and carbon sequestration before this activity, and after this activity they will be prepared for bridge, future-oriented and synthesis activities.

3.2.3 Bridge activities

According to the design principle, the bridge activities have to exploit the connection between scientific, conceptual and epistemological knowledge and practice with the issue of the futures.

Operational recommendation: when designing your activities, keep in mind that the main goal (epistemological goal) is to lead the students to recognize that the epistemic practices like modelling, arguing, posing questions…, typical of the scientific discourse, are thinking tools that can be used to analyze, in the present, any complex context.

Examples from…

Artificial Intelligence module

"Analysis of a complex citizenship context of urban planning: *what social, political, economic, ethical implications can a decision on Artificial Intelligence (AI) have? What stakeholders, values, scientific, technological, social issues are involved in a decision concerning AI?*

This activity guides students to turn the *scientific concepts* related to *complex systems* (concepts developed in activity 1-1bis-6) into *skills* to analyse in depth a problem and to enter the issue of the future.

In order to reach the goals, the "town of Ada" was built, that is the description of an invented town whose Mayor has to address a complex urban planning problem related to the development of Artificial Intelligence.

This activity and the following ones encourage students to analyse and recognise the complexity of a problem (the multiplicity of the stakeholders involved, the complex systems of their relations, …). Moreover the students are guided to share, discuss and negotiate, with their classmates, the values, dreams, concerns and hopes that characterize, more or less explicitly, their analysis of a complex situation and their process of decision making.

Quantum Computing module

"Back to the Future"

This activity builds a bridge from history to the future in the field of ICT. The aim is to show how rapid the technological development of the last decades has been, and that the changes have had wide effects on the whole society. Furthermore, the activity illustrates the difficulty of making predictions and shows how the initial assumptions may lead to erroneous forecasts. Students are encouraged to consider the limitations of their own thinking and broaden their imagination about the future.

The activity begins with analysing a documentary about ICT from the 1980s and 1990s, and exploring fictional predictions of the world in 2015 from the 1980s. The differences and similarities to the present are discussed and their reasons contemplated.

We designed the activity so that it fosters a circular dynamics to connect conceptual and epistemological knowledge

The main learning points of the activity include:

- to recognize the multidimensional impacts of the technological development on society – and the societal development's impact on technology
- to learn to apply the ideas of creative scenario thinking in the field of ICT
- to understand the challenges of predicting and forecasting in the field of ICT
- to understand the role of assumptions in making predictions
- to broaden the imagination about the futures of ICT
- to grasp the feeling of agency regarding the development of ICT and student's own future

Carbon Sequestration module

The activity consists of two recorded interviews with scientists working on solutions to the climate change challenge. One scientist is working on the CarbFix research project on carbon sequestration through mineralization, see activity 3. The other scientist is working on carbon sequestration through reforestation, see activity 2.

Both of these role models address how they became scientists and how they view the potential to influence the future for the better.

The purpose of this activity is to let students relate personally to the research learned about in the previous activities by hearing directly from the people behind them. The scientists represent role models for the students and talk about the potential for STEM careers to change the climate system.

This exposure activity serves to bridge between the two activities in epistemological and conceptual knowledge and inquiry practice to the future-oriented activities (numbers 5 and 6) by relating the scientific content to future possibilities.

3.2.4 Future oriented activities

According to the design principle, these activities guide students to turn conceptual and epistemological knowledge into future-scaffolding skills and competences.

Operational recommendations: when designing your activities, keep in mind that the activities are expected to a) move from the idea of a unique future to the idea of plurality of futures; b) turn the scientific concepts such us *prediction, projection and space of possibilities* into skills for thinking about different ways to realize possible futures scenarios and for thinking about one's own desirable future.

Keep also in mind that the main goal (epistemological goal) is to lead the students to recognize that the linear model of causal explanation of the deterministic prediction somehow does not work in complex contexts: accurate predictions are rarely possible and, usually, not necessary. It is also important that students recognize that it is socially, economically and personally relevant to adopt a way of thinking in terms of possibilities and to explore different ways to realize possible futures (social/emotional goals).

Remember: ***scenario*** *becomes a keyword*.

Examples from…

Artificial Intelligence module

This phase of the module has been developed in two activities

***"Possible future scenarios**: which values, which scientific, technological, social issues are involved in each of them?*

The activity guides students to turn the scientific concepts of *prediction, projection, space of possibilities, scenarios* (concepts developed in activities 1 -7-8) into *skills* to think of different ways to realize possible future scenarios.

In order to reach this goal, three different scenarios for the town of Ada have been designed and students are led to analyse and discuss them. In particular, the students are guided to compare the values they embed, to think about their preferences and idiosyncrasies and to think about the possible events, related to different citizenship decision or plans that may have caused them.

***"Desirable future, back-casting and action planning:** what actions and what action competence can contribute to realize the desirable future?"*

The first part of the activity is closely related to the above activity and guide the students to image their desirable future, where they wish to live.

Quantum Computing module

"Basics of creative thinking"

This activity highlights the importance of creativity in futures thinking and action competence. It shows how even experts struggle in predicting the future and why rigid and formal ways of thinking often lead to bad predictions. The aim is to encourage students to use their imagination and to hold on their dreams and creativity.

At the beginning of the activity, three components of creativity are introduced: expertise, motivation, and creative thinking skills. The paradoxes of creative work are discussed and old wrong predictions contemplated. The predictions are chosen from the field of technology and they link the activity also to technological development. Finally, students are introduced with some blocks and blockbusters to creativity and asked to rethink their own future scenarios. Taking this new, more open-minded perspective to their own course project, they may see new possibilities in their own scenarios.

The main learning points of the activity include:

- to identify the blocks and blockbusters to creativity (also in their own thinking)
- to recognize the role of assumptions and values behind predictions
- to move from the idea of a single future to the idea of plurality of futures
- to learn to point out how all thinking (incl. scientific) and predictions are based on assumptions, values and cultural aspects

Carbon Sequestration module

In this activity, students come to grasp the features of environment and society that make up their world, and compare these features in the past, present and in a desirable future of their imagination.

Students are given interview questions to ask their grandparents or another elderly person. They then answer the same questions about themselves. Finally, they imagine what the answers could be for their theoretical grandchild in a desirable future. Discussion leads students through meaning-making around the kinds of changes that are possible over just a few generations.

3.2.5. Action competence activities

According to the design principle, the activities guide students to activate a return dynamic between present and future.

Operational recommendations: when designing your activities, keep in mind the importance to: a) involve the students in the task of selecting and discussing a problem, determining how to investigate it and deal with it; b) guide the students to *activate forecasting and back-casting dynamic* between present and future; c) lead the students to *plan actions* that can contribute to realize a desirable scenario in which each individual can become an agent and play an active and responsible role; d) guide the students to enlarge their imagination about possible future STEM careers.
Keep also in mind that the main goal (social/emotional goal) is to lead the students to recognize that a) desirable futures are mainly emotional and ethical rather than cognitive; b) each individual has to cope with one's own values and desires, identities, competences and different cultural point of view; c) each individual can become an agent in a complex society and, hence, can play an active and responsible role to create one's own future.

Examples from…

Artificial Intelligence module

"Desirable future, back-casting and action planning: *what actions and what action competence can contribute to realize the desirable future?"*

The activity is focused on the concept of desirable scenarios and, through action competence strategies, the students are guided to play with forecasting and back-casting dynamic between present and future.

The students are guided to work in groups and to plan actions that can contribute to realizing their desirable scenario and to solve, with an original idea, a pressing issue of today.

This is the last activity of the module and, at the end, the students have to present their *success story* in the form of ***back-casting activity***.

Quantum Computing module

"Future Projects"

The future projects activity is planned to run through the whole module. The instructions are meant to be given to students at the beginning of the module so they can start to think of interesting topics and applications right away. During the module, students are supported in realising the future projects that are presented and discussed at the end of the module.

In this activity, students are given the overview of the phases of future projects. Those will form "the backbone" of the whole module. Next, they are asked to choose a topic they are interested in. The choice for a topic is completely up to the students, as long as it involves problems that are of societal/global relevance. After the activity, the teacher will group the students into groups of about four students according to their interests.

The learning goals of this activity include for example:

- to focus on a topic which is personally relevant
- to start thinking about personal and professional visions of the future and their relatedness
- to start realizing one's own potential in taking action to change the future
- to start developing ownership of one's own future

The topics chosen by the student groups of the first two Finnish module implementations include for

example climate change, pollution of the oceans (micro plastics), antibiotic resistance, pensions crisis, cybersecurity (privacy), gene technology and recycling.
Carbon Sequestration module In this final activity, students get the opportunity to demonstrate the mastery they have built up during the module. In the first part of the module, they strengthened their grasp on fundamental epistemological concepts related to climate change and carbon sequestration. In the second part of the module, they measured and calculated the potential for carbon sequestration through vegetation and mineralization. In activity 5 in the module, they gained appreciation for the kinds of change that can happen over a few generations, and projected changes into the future. The purpose of this activity is to synthesize these new understandings and competences and relate them to students' personal and professional visions of the future and their role and purpose in the future. First, students identify a relevant issue to the module that they are interested in working with. Students are grouped according to interest. They then work in their groups to conduct a systems analysis on the issue, evaluate the system to identify leverage points, then design a strategy to influence the system using these leverage points. The final product is the groups' presentations of their stories from the future (back-casted to the present from a future time) of how they achieved success in changing the system and what roles they each played in the change. After the presentations of their success stories, students start on the first step of their strategy plans, which are roadmaps to a desirable future, right away in the present.

Chapter 4

Tools for monitoring and evaluating the implementations

As well as traditional tools (exercises and questionnaires) to evaluate students' understanding of the scientific contents of the modules, further tools have been designed and used to monitor and evaluate students' reactions to the most characteristic aspects of the I SEE modules.

In particular, tools have been designed to evaluate and to monitor:

- students' perception of the future at the beginning and at the end of the module;
- the level of interest, appreciation and involvement about the scientific topics covered and about the future-oriented activities;
- the level of awareness about the different dimensions involved (conceptual, epistemological, future-oriented, action competence) and about their possible connections;
- the level of awareness about the need to develop *a conceptual-epistemological thinking* and *a future thinking.*

In the following we describe some tools we designed. The full tools are linked and can be downloaded. Here we report, for each type of tool, a description about what it consists of, where and when the tool was used and can be used, how long its administration takes, its goals, the structure and/or examples of questions, comments about their application (the weaknesses, the potential and the effectiveness of this tool).

4.1 In-progress questionnaire

Links to the tools (4 tools: student evaluation questionnaire Summer School, feedback questionnaire 1&2 Finland CQ module, questionnaire future studies Iceland, questionnaire Carbon Sequestration Iceland)

Different versions of this type of tool have been designed, always with the same philosophy but adapting it to the specific module in which it was used.

what is	Multiple-choice questionnaire with some open-ended questions
where and when the tool has been used	The tool has been designed to monitor day by day the implementation of the first ISEE module in the summer school (Climate Change module). The tool was then adapted and used to monitor other modules (Quantum Computing and Carbon Sequestration modules) and was administered at the end of the discussion of each specific topic.
goals	Give students opportunity and time to re-think about the topic and /or the activities; help the teaching team to improve and refine the activities in the future or the activities that follow; help the teaching team to know what students gained from taking part, and the extent to which the activities met their expectations.
how long its administration takes	10-15 minutes at a maximum
structure and	At the end of the discussion of each specific topic, 2 multiple-choice questions and 2 open-ended questions were asked.

example of questions	The multiple-choice questions mainly relate to the conceptual aspect of the topic and are of the type • Before attending the course, how familiar were you with the topic (e.g. with electronics, future oriented issues …)? Very much Quite A little Not at all • ……. The open-ended questions refer more to the type of activity and its usefulness for learning and are of the type • For the activities that you ranked most highly please explain why and how these activities worked for you • …….

4.2 Interview protocol

Link to the tool (3 versions: interview protocol for climate change and artificial intelligence modules, Icelandic interview protocol for climate change module, Finnish interview protocol for quantum computing module).

Different versions of this tool have been designed to guide students to discuss the topics covered in the module, adapting it to the specific module in which it was used, but always with the same philosophy; the specific questions can be moreover slightly personalized to focus on the issues of which the student seems to have something interesting to say.

what is	Interview protocol, referring to the different dimensions taken into account in the module: conceptual, epistemological, future-oriented, action competence.
where and when the tool has been used	Students were interviewed at the end of each module, in focus groups or individually
goals	Overall goal To let the students freely express their thoughts about the topics covered in the module. Specific goals To evaluate students' awareness about the skills they developed during the module. Two macro-categories of skills are monitored. a) conceptual-epistemological thinking skills, that is the ability to: - recognize the causal, temporal and logical relationships in the scientific discourse; - distinguish between disciplinary details and comprehensive picture; - recognize science as a laboratory to prepare for the future; b) future thinking skills, that is the ability to: - move from thinking locally to thinking globally (and vice versa); - to move from thinking in the present to thinking in the future (and vice versa); - move from thinking at the individual level to thinking at the societal community level; - think creatively for imagining new possibilities and concrete actions; - balance the need of desire and the necessity of keeping feet on the ground; - think in an inter-disciplinary way.
how long its	

administration takes	About 20/30 minutes
the structure of the tool and/or example of questions	The tool consists of different parts – even if this is not explicit – related to the different dimensions taken into account in the module. Overall consistence of the module The questions concern the structure of the module and the liking and expectations about the topics. The questions are of the type: • Were the topics as you expected? • The module included activities very different to each other. Did you see connections between the activities? Which connections? • ……… Contents of the module The questions relate to the content and aim to explore students' level of awareness about the building of a rational scaffolding. The questions are of the type: • After this course could you explain the meaning of the words determinism and complexity and their differences? • What activities have been important in this regard and why? • …… Perceptions of the future The questions relate to future thinking and aim to explore students' level of awareness about recognising science as a laboratory to prepare for the future. The questions are of the type: • What kind of discussions were activated in the group to outline the desirable scenario? Did you find them interesting? Why? • How did you experience the search for a creative idea to solve a problem? • …..

4.3 Course approval questionnaire

Link to the toll

This tool is an example of a questionnaire online - designed by the University of Bologna - to know to what extent the course met initial students' expectations. The questionnaire gives feedback not only to the teachers' group but above all to the institutions.

what is	Multiple-choice questionnaire with some boxes for optional comments
where and when the tool has been used	At the end of each module implemented by Italian team.
Goals	To collect information about • the usefulness of the course to reflect on oneself; • the usefulness of the course to guide towards future choices (career and school choices); • the level of knowledge required in relation to that which each student has; • the effectiveness of the course from a relational point of view (the relations established with the teacher and the working group);

	• the evaluation of some structural aspects of the course: effectiveness of the activities, clarity of the presentation of the topic, time management.
how long its administration takes	The questions are multiple-choice questions so it does not take long to complete the questionnaire: about 10/15 minutes
the structure of the tool and/or example of questions	The questions concern both the personal reactions of each student – the involvement from the point of view of the content and from the emotional and relational point of view – and the evaluation of the effectiveness of the course structure. The questions are of the type: How much do you think this course helped you • to reflect on your personal characteristics (how you are) • to reflect on your skills (what you can do) • to reflect on your interests (what do you like to do) • to figure out what you expect in terms of the choice you're going to make. the rating is as follows: 1=not at all 2=little 3=enough 4=very 5=completely

Chapter 5

References and list of additional resources

5.1 References

Branchetti, L., Cutler, M., Laherto, A., Levrini, O. Palmgren, E.K., Tasquier,G., Wilson, C. (2018). The I SEE project: An approach to futurize STEM education. *Visions for Sustainability*, 9: 00-00. DOI: 10.13135/2384-8677/2770, ISSN 2384-8677.

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

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.

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

Hancock, T., Bezold, C. (1994). Possible futures, preferable futures. *Healthcare Forum Journal*, 37(2), 23–29.

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, L. (2018). Disciplinary authenticity and personal relevance in school science. *Science Education*, DOI: 10.1002/sce.21458

Leccardi, C. (2009). *Sociologie del tempo*. Soggetti e tempo nella società dell'accelerazione. Eds: Laterza.

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.

Rosa, H. (2013). *Beschleunigung und Entfremdung* - Entwurf einer kritischen Theorie spätmoderner Zeitlichkeit, Suhrkamp (Eng. Trans: *Acceleration and Alienation* - Towards a Critical Theory of Late-Modern Temporality, 2015).

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.

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.

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.

5.2 Additional resources

If you want to deepen about the teaching learning model (SSI-TL model) that inspired the I SEE approach we recommend you to read:

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

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* (pp. 176–192). New York: Routledge/Taylor & Francis Group.

If you want to deepen about the action competence approach in which students become more conscious of the decisions and actions they take, we recommend you to read:

Jensen, B. B., & Schnack, K. (1997). The action competence approach in environmental education. *Environmental Education Research*, 3(2), 163-178.

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.

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.

If you want to deepen on transformative learning that fosters students' personal, societal and vocational agency and identity we recommend you to read:

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.

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.

Roth, W.M., & Lee, S. (2004). Science education as/for participation in the community. *Science Education*, 88, 263-291.

If you want to deepen on the dimensions of science that are expected to give students a sense of disciplinary authenticity we recommend you to read:

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

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

Kapon, S., Laherto, A., Levrini, L. (2018). Disciplinary authenticity and personal relevance in school science. *Science Education*, DOI: 10.1002/sce.21458

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.

Viennot, L. (2006). Teaching rituals and students' intellectual satisfaction. *Physics Education*, 41, 400-408.

If you want to deepen about future-scaffolding skills within STEM education, we recommend you to read:

Levrini, O., Tasquier, G., Branchetti, L., Barelli E. (under review). Developing future-scaffolding skills through Science Education. Submitted to *International Journal of Science Education (minor revisions)*

If you want to deepen about topics that concern cross-cutting fields and that can be relevant in students' futures, both at the personal, vocational and societal level we recommend you to read

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.

If you want to deepen on "Futures Studies" we recommend you to read:

Voros, J. (2003). *A generic foresight process framework*. Foresight, 5(3), 10-21.

Hancock, T., Bezold, C. (1994). Possible futures, preferable futures. *Healthcare Forum Journal*, 37(2), 23–29.

Of interest are also:

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. Aggregate Report, Eurobarometer Qualitative Study, June 2015. Retrieved on June 4, 2018 from: http://ec.europa.eu/commfrontoffice/publicopinion/archives/quali/ql_futureofscience_en.pdf

Ministry for Education, Science and Culture (2014). The Icelandic national curriculum guide for compulsory schools - with subjects areas. Reykjavík: Mennta- og menningarmálaráðuneyti.