THE EDUCATIONAL MODEL

Table of contents

Abbreviation / Acronym	Description
SDG	Sustainable Development Goals
WP	Work Package
CLAUDI	Climate Auditorium
QEC	Quality Evaluation Committee
IPCC	Intergovernmental Panel on Climate Change

Partner short name used in this document	Full Partner Name
EA	Ellinogermaniki Agogi Scholi Panagea Savva A
FG	Fondazione Golinelli
RDPSEC	Regional Directorate of Primary and Secondary Education of Crete
UBREMEN	University of Bremen
UH	Helsingin Yliopisto (University of Helsinki)
UNIBO	University of Bologna
UOC	University of Crete

1 Introduction

The goal of this document is to present the educational model for teacher training, developed in CLIMADEMY (Section 2).

The model is mainly targeted to the local teacher trainers.

It aims both to contribute to providing a «pedagogical identity» to the activities carried out within CLIMADEMY and to convey the teacher trainers the message that the activities with the teachers do not have only to teach new scientific contents but also new pedagogical knowledge and methods.

The model has been built starting from a study on teachers' needs (Section 3.1) that oriented the approach to adopt to address them (Section 3.2).

Section 3.3 includes the guidelines for designing and implementing teacher training activities. The guidelines (Section 3.3) include:

- Recommendations to analyse or reconstruct scientific contents for educational purposes *(epistemic-cognitive dimension);*
- Recommendations to imagine and design active and inclusive learning environments *(Pedagogical (classroom) dimension);*
- Recommendations to co-design and inhabit interdisciplinary contexts as boundary zones *(relational and institutional dimensions);*
- CLIMADEMY competence framework as a reference to point out the general and specific goals to pursue through the activities *(socio-cultural dimensions)*;
- Assessment references and tools.

The guidelines are built on the results of Science Education Research. In order to make the research references more user-friendly, we have pointed out key-messages and elaborated examples of how the key-messages can be conveyed and discussed with trainee teachers.

Furthermore, the model is illustrated through a template aimed at orienting teacher training activities of co-learning, co-designing and co-teaching. The template is then used as a tool to describe prototypes of activities that exemplify the pedagogical model (section 4).

Since assessment is always an issue for the teacher, we added two Annexes where the relations between competences and learning outcomes are elaborated (Annex A) and further assessment guidelines and examples are described in more detail. (Annex B).

The deliverable is the result of a collaborative process that we carried out in a series of workshops, teacher training activities, presentation of the model in international conferences in physics and science education, during which we shared research frameworks, examples of teacher training activities and examples of analysis of such activities.

The structure of the deliverable has been designed by UNIBO (Olivia Levrini), but the writing of the specific sections has been carried out by: Dimitris Stavrou, Emily Michailidi (sections 3.3.1 and the second part of 3.3.2); Janina Taurinen, Juliana Friedrichsen, Anniina Katja Lauri, Suvi Lintuvaara , Laura Riuttanen (section 3.3.3); Clemente Rossi, Emma D'Orto and Giulia

Tasquier (Section 3.3.4); Jari Lavonen (Section 3.3.5 and Annex B); Thalia Tsaknia (Annex A). Sara Satanassi, Giulia Tasquier, Paola Fantini provided hints for Sections 3.1 and 3.2.

Athina Ginoudi, Ioannis Metaxas, Giorgia Bellentani, Francesco Martinelli, Stefania Zampetti, Simon Bittner, Marius Dan, Mihalis Vrekoussis, together with all the colleagues mentioned above, actively participated in the workshops, by offering examples of activities of by providing important feedback and revisions to the document.

Maria Kanakidou, Nikos Kalivitis participated in the workshops to guarantee consistency and fruitful links among the Work Packages.

2. Project Description

This deliverable on the "**Educational Model for teaching training**" reports the work done in WP3 of CLIMADEMY project.

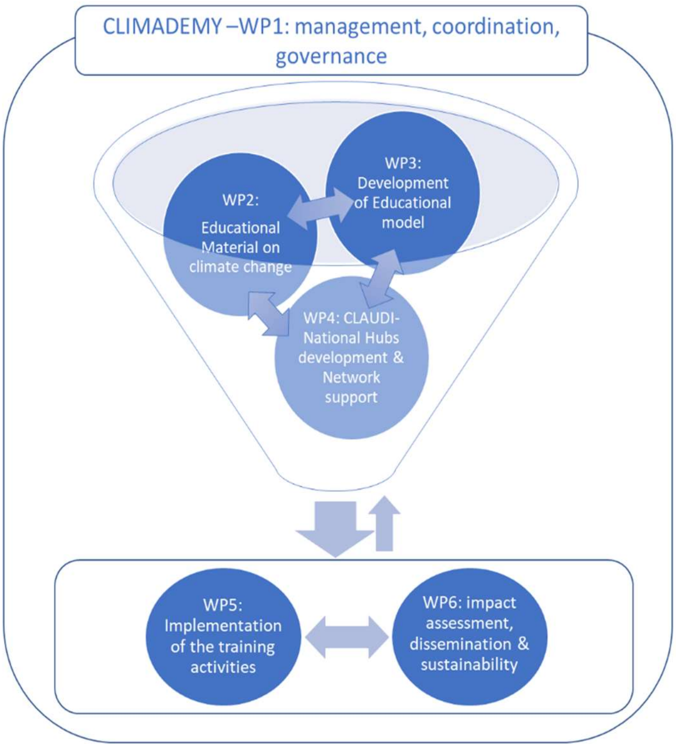


Fig. 2.1 – CLIMADEMY PERT

The Climademy project is divided into 6 work packages, listed below.

- WP1: Project management, coordination and governance
- WP2: Educational materials on climate change
- WP3: Development of educational model for teacher training

- WP4: Establishment of a common virtual CLAUDI and National Hubs
- WP5: Implementation of the Training Activities
- WP6: Impact assessment, dissemination and sustainability

In WP1 the project coordination and management bodies are established, in order to ensure the general project coordination and monitoring of progress. In WP2 educational material are collected and further developed to understand the main drivers of climate change. WP3 focuses on the development of an educational model suitable for teacher training. WP4 is concerned with the establishment of the four national hubs and the development of the virtual CLAUDI platform. The aim of WP5 is to organize the large-scale implementation of the Training Activities leading to an enhanced notion on Climate Change Education of participating teachers and eventually to their professional development. Finally, WP6 is concerned with the dissemination and sustainability of the project deliverables.

3. Educational Model for teaching training

Sections 3.1 and 3.2 are the results of a progressive discussions of the model in contexts of teacher training (in particular, in national and international CLIMADEMY summer or autumn schools and events[1]) and in national and international conferences in physics or science education. The text has been submitted to be published on the proceedings of the *4th World Conference on Physics Education 2024, Kraków, Poland* (Levrini et al., submitted).

3.1 Teachers' needs and challenges in teaching Climate Change themes

The pedagogical model was gradually refined to meet teachers' needs and to clarify CLIMADEMY's stance on the following questions: *What type of materials and educational support do secondary school teachers need to incorporate climate change into their teaching? What challenges does climate change education pose to science teachers and the school ecosystem? What institutional, disciplinary, epistemological, and relational transformations are needed to include climate change in school curriculum and, hence, in teacher education?*

To gauge teachers' needs, we organised focus-group interviews with 41 teachers and student-teachers across the project's four hubs (Rossi, 2024). The sessions were transcribed and examined through a bottom-up thematic analysis (Braun & Clarke, 2024), revealing four principal clusters of needs:

[1] The most important were; First Italian Italian Hub Summer School, Bologna, Italy 26 – 29/06/2024; International Professional Development School in Athens, Greece, 30/6 – 3/7/2024; Finnish Hub Teacher's Climate Change Forum 2024, Hyytiälä Forest Station, Finland, 1/9 – 3/9/2024; Greek Hub Autumn School, Agios Nikolaos, Crete, 3 – 5/11/2024; German Hub Winter School, Bremen, Germany, 04/12 – 06 /12/2025; Italian Hub Winter School, Bologna, Italy, 27 – 28/02/2025 & 1/03/2025; CLIMADEMY final Conference & Teachers' Climate Change Forum, Hyytiälä Forest Station, Finland, 31/3 – 3/4/2025.

- *Disciplinary* – The need to enrich and improve their content knowledge, and to redefine teachers' sense of expertise.
- *Educational-practical* – The need for concrete but flexible, open-ended resources or curriculum materials, and pedagogical approaches (teaching and assessment methods).
- *Orienteering* – The need for goals and shared values that guide instructional choices.
- *Institutional* – The need for a supportive and socially responsive school system.

As expected, teachers repeatedly emphasised the need for current, expanded knowledge—particularly on interdisciplinary themes linked to climate change and sustainability. They explained that traditional disciplinary silos often leave them ill-prepared to tackle emerging areas within and beyond STEM, generating both epistemological and methodological uncertainty. As one Italian teacher observed:

«There are a lot of things that I don't know. I haven't studied them.»

The comment underscores how sharply climate change stretches educators' sense of expertise: they can no longer rely on deep mastery of a single field but must also build cross-disciplinary insight for which their training did not prepare them.

Alongside this call for broader knowledge, the teachers pointed to a parallel need for novel resources—materials that are flexible, current, and able to span the generational divide in environmental awareness and digital fluency. Several remarked that such resources should target students who already possess, in certain respects, more advanced skills than their teachers. As one German participant offered from an intergenerational standpoint on the climate crisis:

«I think young people have enough energy, potential, and maybe even ideas to make it [climate] *turn back fast… We can train them and give input as teachers to look for solutions.»*

A strong theme in the focus groups was the aspiration to affect students' beliefs, values, and actions. Teachers recognized that delivering factual knowledge is no longer sufficient; they also need strategies to influence how students perceive and respond to real-world challenges. As a Greek teacher stated:

«My role is to alter the way they [students] *think and the way they act.»*

Finally, teachers stressed that tackling climate change in schools hinges on solid institutional backing. They noted that interdisciplinarity affects more than lesson content and classroom practice: it also reshapes curricula and requires systemic changes—scheduling, assessment methods, and administrative support among them.

Insights from the focus groups show that climate change strikes at the heart of teacher professionalism, which is typically anchored in subject-specific expertise. Professional knowledge certainly includes pedagogy, classroom management, and policy awareness (Gess-Newsome, 2015; Kulgemeyer & Riese, 2018), yet deep subject mastery remains central in many educational traditions.

Disciplines are more than textbook categories; they scaffold how generations connect, how colleagues collaborate, and how institutions are organised—schools into "subjects," universities into "departments," research into areas and ERC sectors. They also shape identity, forming cultural communities built on the core values each field upholds.

Climate-change education pushes teachers—and the wider system—to reconsider their views on knowledge, teaching approaches, relationships with students and colleagues, and institutional structures. This wide-ranging redefinition of teacher identity and expertise sits at the core of preparing the next generation for one of today's most urgent challenges, and it has informed the design of our pedagogical model.

3.2 Overview of the educational model

The educational (or pedagogical) model of CLIMADEMY was designed to support teachers along all the needs dimensions that emerged:

- *Epistemic and Cognitive Dimensions*: The model had to support teachers in finding their new position with respect to knowledge by helping them to question disciplinary barriers that date back to 19th-century models of knowledge organization (Satanassi et al., 2023) and search, in their disciplines, for ways to equip their students to deal with complex interdisciplinary phenomena.

- *Pedagogical Dimension*: The model had to support teachers in creating effective and engaging learning environments where students are guided to make sense of complex climate change phenomena through project-based or inquiry-based learning (Vesterinen et al., 2025, in press). This promotes an understanding of climate change, engagement, a sense of agency, and active hope (Monroe et al., 2019; Jorgenson et al., 2019)

- *Relational Dimension*: The model had to provide teachers with support and experience inhabiting "boundary zones" (Akkerman & Bakker, 2011; Satanassi et al., 2023) where multidisciplinary and multistakeholder dialogue and interactions thrive. Collaboration among colleagues, students, parents, school principals, and external experts becomes vital for effective climate education (Zhai et al., 2024). This requires building new professional relationships that transcend traditional subject boundaries and hierarchies.

- *Institutional Dimension*: The model had to support teachers in searching, in their schools, in space-time contexts for interdisciplinary interventions. Teachers operate within a normative context shaped by strict time and space organization, curricula, and assessment practices. Introducing climate change as an interdisciplinary subject tests these structures and calls for significant institutional support (Levrini et al., 2024).

- *Socio-cultural dimension* - the model had to provide teachers with some orientation to prioritize teaching goals.

Based on all these considerations, we finally outlined our pedagogical model and its structure (see Fig.3.1). Here, by educational (or pedagogical model), we mean a set of theoretical frameworks, examples of resources, and practices, elaborated by research in science education, that can be used in teacher education contexts where teachers are supported to:

- analyze, shape, and re-generate content knowledge;
- experience inclusive and engaging learning environments and psychologically safe forms of participation;
- co-design, co-learn, and co-teach in interdisciplinary boundary zones;
- question institutional barriers among disciplines;
- share social, political, and epistemic values and goals.

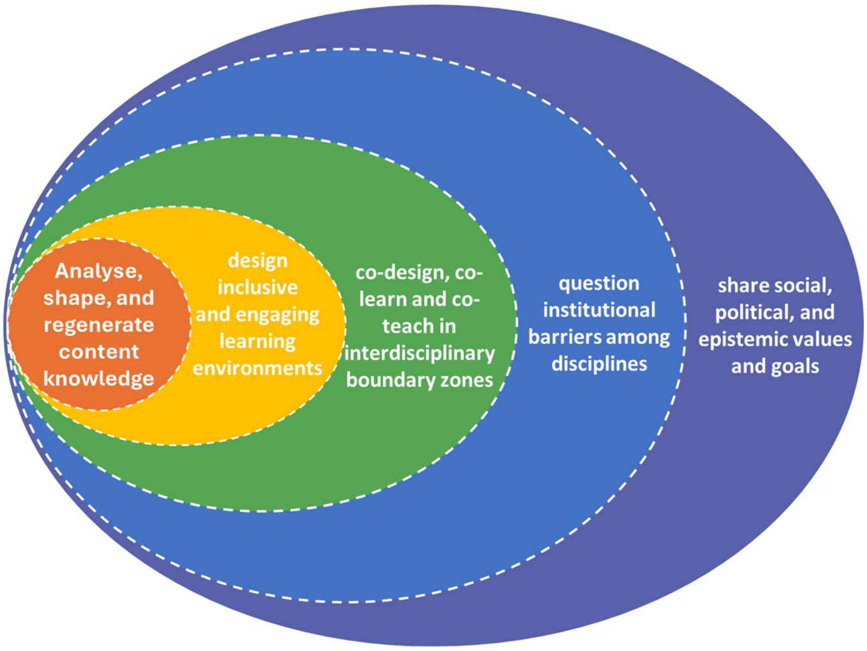


Fig. 3.1 – Multi-dimensional structure of CLIMADEMY pedagogical model

In the following we present an overview of the research frameworks that we selected and used to support the teachers along the various dimensions.

A. *Epistemic-cognitive dimension*

CLIMADEMY adopts the Model of Educational Reconstruction, MER (Duit et al., 2012), as the principal reference to design new materials, select, value, and/or elaborate on existing materials used in the teacher Academy. In some teacher workshops, the Educational Reconstruction for Teacher Education (ERTE) model and a modified Content Representation (CoRe) tool (Loughran et al., 2018) have been used in the design of educational materials and pedagogical approaches because they take into account climate values and competences in addition to knowledge. Moreover, the modified CoRe-tool considers using digital tools in teaching and learning climate-related issues.

The combination of the three models is used in CLIMADEMY to convey the following messages to both the teacher trainers and the trainees:

(Key message 1) *When planning instruction, first, equal attention should be given to the science content (values, knowledge, and skills) to be learned, students' cognitive and affective variables, as* *well as previous conceptions and experiences linked to learning the content. Second, pedagogical approaches, instruction, and assessment methods should be selected carefully to engage students in learning complex climate change phenomena and support their agency. Third, the interdisciplinary nature of climate change should be taken into account when planning the instruction.*

(Key message 2) *"The content structure for instruction is somewhat more elementary (from the science point of view) but richer than the science content structure"* (Duit et al., 2012).

In CLIMADEMY, the involvement of atmospheric chemists and physicists led to building a knowledge base on the drivers and impacts of climate change, which serves as both the foundation and goal for teaching activities. Teachers and teacher educators, in their hubs, are involved in activities to elaborate on this knowledge to pursue the goals: to guide their students to understand the basic concepts and their epistemological meaning, make sense of it, appropriate it to develop sustainable ways of thinking and, consistently, the capacity to take agency to promote sustainability. To pursue these goals means to operate on knowledge through both a process of *elementarization* and *complexification* (Duit et al., 2012). Elementarization implies that scientific knowledge is shaped by teachers and science education experts so as to be made accessible to secondary school students. Complexification means that knowledge has to be enriched to exploit its educational, social, and cultural potential not only to promote processes of meaningful learning but also to activate critical thinking and creativity and foster active hope needed to imagine desirable futures and develop a sense of agency.

MER and CoRe tools have been used for structuring teachers' knowledge while they have been guided to question and shape scientific knowledge, design the modules, and elaborate a comprehensive framework for assessment.

A more detailed description of recommendations coming from the MER and CoRe is reported in Section 3.3 (A).

B. Pedagogical (classroom) dimension

To guide teachers in designing and implementing class activities, CLIMADEMY adopts two main kinds of models.

The first type refers to the so-called Participant frameworks and the mentoring model MERID elaborated in Science Education Research (Michailidi & Stavrou, 2021). These frameworks have been selected to prompt, during the teacher education activities, questions like:

Knowledge generation: Where does knowledge come from (teacher, students, external resources, etc.)? Who or which is supposed to be the "source of knowledge"? Knowledge could also be inquiry-based or an outcome of envisioning or designing.

Knowledge distribution flow and accountability: How is the knowledge distributed in the class? Who has the accountability to speak ("Who can speak what and when?")

Teacher role and discourse pattern: what is the role of the teachers? Is she/he supposed to lead a "directive discourse pattern oriented to test and evaluate" or an "indirective pattern aimed to facilitate the ideas exploration or a collective discussion"?

The second type is an operational model developed by Barquero & Bosch (2015) within the paradigm established by the anthropological theory of the didactic (ATD) for mathematics education (Chevallard, 1992). This model is known as "Study and Research Paths for Teacher Education (SRPs-TE) (Barquero et al., 2018). This model has already been modified and used in the Erasmus + project IDENTITIES. CLIMADEMY, for its activities, refers to the version developed for IDENTITIES and here further elaborated. In particular, the model is used to guide teachers in articulating their processes of co-learning, co-designing, and co-teaching in four phases, facilitated by a member of the hub who plays the role of facilitator:

- *Teachers as explorers:* Group activities are organized to break the ice, brainstorm, share goals, and have a first look at what emerges from and around them. In this type of activity, all the participants are invited to share their knowledge, experiences, and beliefs.
- *Teachers as students:* Activities are organized to make participants familiar with new content or activities that could, to a certain extent, be also reproduced and used in an ordinary secondary classroom. This type of activity is supposed to convey novel knowledge or methods to the teachers.
- *Teachers as analysts:* Activities are organized to invite the teacher to hire an external "meta" position from which to analyze the materials and the activities they have experienced in the previous type. They are invited to change the role and adopt the " analyst " role. At this stage, educators introduce some tools to progress collectively with participants on the analysis of the materials
- *Teachers as designers:* in these activities, teachers share secondary school experiences with other teachers. Through the presentation of real case studies in secondary school, participants are expected to elaborate on how to use the tools to re-design and adapt the activity for their classes.

C. Relational and institutional dimensions

The epistemic-cognitive and pedagogical frameworks were generally well-received when presented and discussed with the teachers. More challenging were the frameworks we introduced to question the disciplinary structures as a form to organize the relational and institutional dimensions. The relational dimension is crucial since climate change is an intrinsically inter-multi-trans-disciplinary theme that requires teachers and teacher trainers to develop competences of co-learning, co-designing, and co-teaching in genuine inter-multi-trans-disciplinary contexts. Thus, to support teachers to develop such competences, we adopted the framework of Akkerman and Bakker (2011). This framework guides to create and inhabit inter-multi-transdisciplinary spaces as boundary zones. The metaphor of the boundary is the basis for developing a conscious interdisciplinary language that is fundamental to acting and thinking as boundary people, recognizing the boundary objects, and naming boundary-crossing mechanisms.

Specific studies we are carrying out (Satanassi et al., 2023; Branchetti & Levrini, accepted) are showing how delicate and complicated it is to:

- Inhabit a boundary zone and learn to "speak" the language of interdisciplinarity, i.e., the language to name and recognize processes of boundary-making and boundary-crossing mechanisms;
- Hybridize practices, negotiate meanings, rediscover one's own positioning of competence;
- Accept the ambiguity and interpretative flexibility of concepts and, at the same time, be able to recognize the specificities and different mechanisms of "disciplinary closure of meanings" (boundary making) (Satanassi et al., 2023);
- Establish communication connections and build translation methods between one area of knowledge and another;

- Activate a dialogic process of "othering," defining one practice in the light of another, outlining analogies and differences between practices (Branchetti & Levrini, accepted);
- Put oneself in perspective and know how to put oneself in other perspectives (perspective making and taking) (Akkerman & Bakker, 2011).

When these difficulties are overcome, new institutional spaces are created, and school culture can significantly change.

D. Socio-cultural dimension

Maybe the most interesting discussions with the teachers concern the last sphere and the issue of getting oriented in current society and sharing the competencies that education should contribute to forming. For this purpose, CLIMADEMY developed a competence framework articulated in four competence areas (see Fig.3.2)

Fig. 3.2 – CLIMADEMY competence framework

These areas expand on the GreenComp framework (Bianchi et al. 2022) by incorporating specific knowledge, skills, and attitudes related to climate change. Like the GreenComp, the CLIMADEMY competence framework stresses the emphasis on approaching competences and needs systemically to:

- Elevate *Values building* at the rank of a competence area, requiring knowledge, skills, and attitudes;
- Expand the *Scientific inquiring* to embrace complexity and overcome the traditional deterministic, linear, and reductionist approach that historically shaped the Modernity project and that is now revealing its climate, social, and economic non-sustainability (Levrini et al., 2024);
- Introduce futures thinking in education, educate to envision alternative possible future scenarios (Levrini et al., 2019; 2021; Rasa et al. 2022; Tasquier et al., 2023);
- Articulate individual, collective, and political agency to problematize harmful hope and a general sense of hopelessness.

3.3 Guidelines for designing and implementing teacher training activities

In this section, more detailed descriptions of the frameworks we chose to support the teachers along the various dimensions are reported.

A. Epistemic-cognitive dimension - Recommendations to analyse or reconstruct scientific contents for educational purposes

The research-based recommendations, provided here to support teachers to design and implement effective teaching modules, come from the Model of Educational Reconstruction (MER), the Educational Reconstruction for Teacher Education (ERTE) model and a modified Content Representation (CoRe). We first illustrate the basic ideas of the models, and then we list key-questions that can orient the design activities.

The Model of Education Reconstruction and the Content Representation (CoRe) tool

MER has been designed and refined by German scholars (e.g. Duit et al. 2012). As it is illustrated in Fig. 3.3 the MER consists of three closely interrelated components.

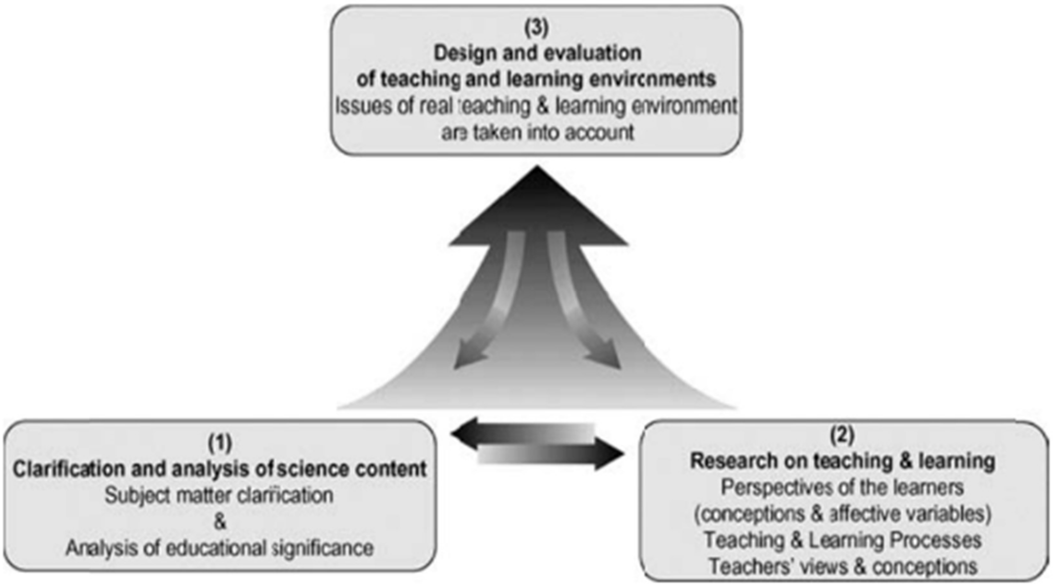


Fig. 3.3. Model of Educational Reconstruction (Duit et al., 2012)

Component 1 – Clarify & Analyse the science content from an educational perspective

This component orients instruction designers to assume a special take and position with respect to scientific contents of the modules and accept that contents are rich and complex enough to be "analysed", "worked" and "shaped" from many different perspectives. Specific science conceptions and the content structure reveal special nuances and meaning if they are clarified and analysed from an educational point of view. For this reason, the MER stresses the need to consider two processes as closely linked: clarification of subject matter and analysis of its educational significance. The content knowledge and structure of a certain domain have to be transformed into a content structure for instruction, *as the two structures are substantially different.* Roughly speaking, the second one has to activate cognitive resources to be approached and learned. In order to activate such a transformation, the scientific contents have to be first *elementarized* to become accessible for learners but also *enriched* with epistemological and cognitive elements that foster processes that make sense to the learners. In this process, science content issues and issues of learners' perspectives (their conceptions and views about the content as well as affective variables like their interests and science learning self-concepts) have to be taken into account and put in resonance.

Component 2 – Account for research on teaching and learning

*T*he process of clarification, analysis of science content, and the process of constructing the content structure for instruction all need to be based on empirical research on teaching and learning. It is important to take into account both the research on learners' perspectives that investigates their ideas and affective variables, and the studies on teaching that investigate orchestration processes and the role of instructional methods.

Components 3 – Design & evaluate the teaching & learning environments

The third component comprises the design of instructional materials, learning activities, and teaching and learning sequences. It also presents the learning activities that have to take under consideration all the aforementioned dimensions.

According to MER, the goal to facilitate the recognition of the educational potential of the material can be pursued by including, in the presentation of the instructional materials and learning activities, a description of:

a) the basic scientific concepts (the result of *elementarization*) of the activities;

b) their educational *enrichment* and relevance;

c) research references on students' conceptions.

The Model of Educational Reconstruction provides a theoretical framework as well as guiding principles for educational design in science education, both at research level (for which it was originally developed), and at school level. Accordingly, it can also be used as a framework for teacher education and further professional development by being appropriately transformed into a model for designing guidelines for science teachers' education. This model of Educational Reconstruction for Teacher Education (ERTE, Van Dijk & Kattmann, 2007), by analogy with the MER, aims to design effective science teacher training environments so that they are able to design their courses or implement teaching modules and activities based on the principles of constructivist teaching. The ERTE model is based on the idea that the content for teacher education needs to be 'reconstructed' for teaching taking into account empirical research on teachers' views on teaching and learning, their needs and their knowledge. In particular, in the ERTE model the following research domains are integrated in MER: (1) Guidelines for teacher education, (2) Clarification of educational design concepts, and (3) Empirical research on teacher education. These elements are strongly interrelated and they influence each other mutually.

Lougharn et al. (2008) have suggested a list of eight questions, supportive for the planning of lessons and named the collection of questions as *The Content Representation (CoRe) tool*, which could be used for structuring pedagogical content knowledge (PCK) in order to support students' learning. For the purposes of CLIMADEMY, the original CoRe tool was slightly modified for better taking into account climate education needs and use of digital tools in teaching and learning. The questions, which guide the design of lessons in this modified CoRe tool are:

1. What do students need to learn about the climate-related topic or what are the core ideas/big

ideas/key concepts and models related to the topic? Should you take into account the multidisciplinary nature of the topic? Do you have specific aims related to the learning of attitudes, values and skills or the use of digital tools in learning?

2. Why is it important (meaningful and relevant) for students to learn this climate related topic (need-to-know)? Is it possible to influence students' engagement through choosing an appropriate context for learning or take into account environmental, economic, political, psychological views related to the topic? Why/Why don't students need to use digital tools in learning?
3. What else do you know about this topic - not going to teach students (the level of content)?
4. What do you know about students' everyday experiences in the area of the topic (values, knowledge and skills)? What experiences students have about the planned use of digital tools?
5. What do you know about students' conceptions/ misconceptions related to the topic and how does it affect the teaching of the topic?
6. How does context influence the teaching of this topic (student, classroom and school context)? What kind of digital tools are available at school considering your aims? Do you need to book the digital tools beforehand?
7. What kind of pedagogy you are planning to use, and how well the pedagogy suited for the topic and planned use of digital tools (knowledge-in-use)?
8. How are you going to assess student learning, including the use of digital tools (knowledge-in-use)?

In CLIMADEMY, the MER, CoRe-tool and ERTE frameworks act as research references to select the following prompt questions to be used, in the teacher training activities, to spark discussions and analyse, with the trainees, the materials and activities.

Analysis of science content:

- Which are the fundamental scientific theories and concepts involved in this topic on climate change, and where are their limitations? A climate topic always includes climate related values, attitudes, knowledge and skills. Often a climate related topic is multidisciplinary by nature and, therefore, in addition to science knowledge, also environmental, economical, societal and psychological knowledge should be taken into account. Moreover, the topic has often personal, local and global dimensions.
- What basic phenomena or basic principles; what general laws, criteria, methods, techniques, values or attitudes; what inquiry and design skills may be addressed in an exemplary way by dealing with climate change content?
- Which social implications are associated with the scientific concepts and/or the topic at issue?
- Which fields of application are affected?
- What is the relevance and significance of the content and the topic for students' future life, from a personal, social or vocational point of view?

Students' perspectives:

- What attitudes, values, subject matter knowledge and skills do students have at their disposal? Are they expression of active hope or deep anxiety toward future envisioning?
- How are the climate-related scientific concepts represented in students' perspectives?

- Which conceptions, i.e., conceptual frameworks and concepts, are used by the students?
- How do alternative frameworks and conceptions of students correspond with scientific theories and concepts?

Design of teaching & learning environments:

- What are particular cases, phenomena, situations, experiments that allow making the structure of the referring content interesting, worth questioning, accessible, and understandable for the students?
- Which are the most relevant elements of the students' conceptual framework to be respected?
- Which conceptions of students correspond with scientific concepts in such a way that they can be used for a more adequate and fruitful learning?
- What are the conditions (e.g., interests, motivations, classroom climate, power structures in classrooms) that have to be arranged in order to support learning the intended science content (to support conceptual change)?

B. Pedagogical (classroom) dimension - Recommendations to imagine and design active and inclusive learning environments

The second layer of our model concerns, explicitly, pedagogical principles. We use the term "pedagogical principles" to name recommendations for the implementation of the activities in a real context of teacher education. They can also be adopted in classes of secondary school students and, in this sense, they can also be the object of formation in the contexts of teacher education. The principles are important to maintain or exploit the innovation potential of the materials, foster active engagement of the learners and, mainly, to reflect on how knowledge is generated, shared, and made circulate in a group of learners. For this reason, the models presented here have been chosen to address the second cluster of needs of teachers, related to how to manage, in a class, the relation with peers or with students, mediated by the knowledge on climate change.

In the following, we introduce the concept of *participant framework* to illustrate the sense of pedagogical principles and to suggest an activity to discuss them in contexts of teacher education or in contexts of co-learning, co-designing, and co-teaching, where a member of the group plays the role of facilitator.

Then, we present, two frameworks: the MERID framework and SRPs-TE, to provide further suggestions for implementing the activities in the teacher training activities.

The concept of participant framework

A way to break the ice and open the discussion on the pedagogical principles in contexts of teacher education is to introduce the concept of *participant framework.* This concept can help to provide criteria to characterize the dynamics of teaching/learning within their class. For this reason, we present them as prompts that can be used with the teachers to guide them to reflect on their own practices.

Participant frameworks*:* structures that outline class scenarios where interactions take place by describing the rights, roles, and responsibilities of participants in a setting with respect to the issue of "Who can speak what and when?" (Hegedus & Penuel, 2008).

Examples of participant frameworks that can be discussed with the teachers are the following ones, taken from Tabak and Baumgartner (2004) and freely elaborated:

- **"teacher as monitor":** this participant structure is characterized by an asymmetrical relationship between the teacher and the learners, where the nature of instruction is the following: the teacher is the repository of the knowledge, she/he initiates the discourse, asks about procedures, tasks and completion of task-related milestones. At the end, it is up to the teacher to evaluate and close the conversational routine.

- **"teacher as mentor":** this participant structure is still characterized by an asymmetrical relationship and the nature of instruction is also explicit, but unlike in the monitor framework, this participant framework leaves "room for interpretation, negotiation, and adaptation of ideas, rather than the testing and evaluation" (Tabak & Baumgartner, 2004, p. 403). In this participant structure, knowledge can be also generated by the students and "the teacher tries to help the students to align their thinking and actions with scientific norms without dictating actions or explanations" (Tabak & Baumgartner, 2004, p. 403).

- **"teacher as expert-partner":** here the teacher assumes a different posture, "the teacher presents herself as a peer" and "joins the group for a few minutes and takes part in their investigation as a genuine member of the group" (Tabak & Baumgartner, 2004, p. 403). In "teacher as partner" the teacher is no longer the sole authority and multiple students are authorized to speak; knowledge is distributed and can be generated by the single participants and/or by the classroom interaction.

- **"teacher as partner":** here "the teacher presents herself as a peer" and "joins the group for a few minutes and takes part in their investigation as a genuine member of the group" (Tabak & Baumgartner, 2004, p. 403). In "teacher as partner" the teacher is no longer the sole authority and multiple students are authorized to speak; knowledge is distributed and can be generated by the single participants and/or by the classroom interaction.

- **"teacher as moderator of the discussion":** here the teacher chairs a discussion and does not take sides saying who is right. Knowledge is not on the teacher, and it is assumed to be distributed and generated by the single participants and/or by the classroom interaction.

- **"teacher as perspective-maker":** this structure can emerge in co-teaching contexts, where each teacher plays the role of an expert of one possible view. Knowledge is distributed among the teachers and the students, and it can be generated by the single participants and/or by the classroom interaction.

In the previous description, the criteria used to characterize a participant framework are:

- Knowledge generation: Where does knowledge come from? Who is supposed to be "source of knowledge"?

- Knowledge distribution flow and accountability: How is the knowledge distributed in the class? Who has the accountability to speak ("who can speak what and when?")

- Teacher role and discourse pattern: what is the role of the teachers? Is she/he supposed to lead a "directive discourse pattern oriented to test and evaluate", or to lead an "indirective pattern aimed to facilitate the ideas exploration or a collective discussion"?

To activate a discussion in context of teacher training, we suggest using the following schematic pictures (Fig. 3.4 a, b, c, d) as representation of classroom dynamics and ask the teachers to describe them in terms of the previous criteria. Cases a), b) represent the most familiar way to imagine a classroom dynamics. Case c) is supposed to represent a case of co-teaching and, already this one, can create some discomfort, touching some elements of teacher professional identity: "being THE source of the entire knowledge". In the digital era and in the society of uncertainty where complex and inner interdisciplinary themes like climate change have to be addressed in school, a more realistic picture of what classroom dynamics should be imagined is represented in Fig.8(d). The discussion on this image can be very fruitful to invite the teachers to imagine or re-imagine of their role and their position with respect to knowledge, students, colleagues and society more in general.

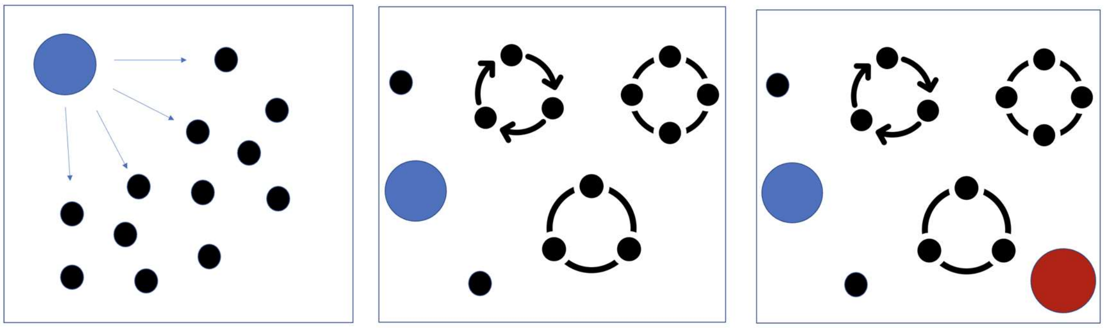


Fig. 3.4 (a, b, c) - Classroom dynamics representations. Fig. 8.a) suggests a typical lecture dynamics, where the teacher (blue dot) exposes knowledge (arrows) to the students (black dots); Fig. 8.b) suggests a teamwork, facilitated by the teacher (blue dot); Fig. 8.c) suggests a case of co-teaching during teamwork.

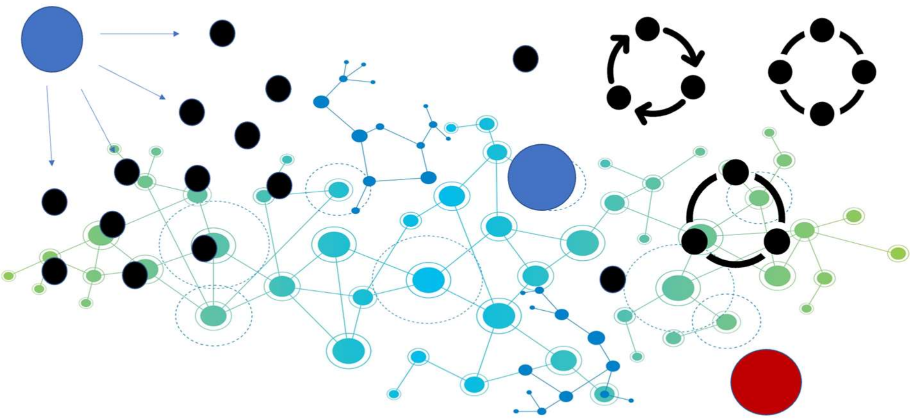


Fig. 3.4 (d) – Classroom dynamics representation in the digital era, when knowledge generation and sharing cannot avoid the presence of the web.

The MERID model

As for the role of teacher trainers, in CLIMADEMY we suggest to implement the pedagogical principles embedded in what is called “educative mentoring”.

Educative mentoring is a collaborative and reciprocal relationship within which both the mentor and mentee engage in inquiry into practice aiming at both parties’ professional growth (Bradbury, 2010). In this regard, educative mentoring can be considered as a more mediating practice that promotes the active construction of knowledge within real educational contexts. The goal of educational mentoring remains to meet the immediate needs of the mentee-teachers, but also to promote a long-term professional development of mentees through their initiation to an exploratory attitude towards their daily practice (Bradbury, 2010). As such, educative mentoring presents many points of convergence with the definition of learning communities by Stoll et al. (2006) as “a group of people sharing and critically interrogating their practice in an ongoing, reflective, collaborative, inclusive, learning-oriented, growth-promoting way operating as a collective enterprise”. Therefore, by the conjunction of mentoring and communities of learners, mentees have the opportunity to benefit from the shared knowledge and the social interaction with both the more experienced mentor and peers as well.

The practices and the roles mentors assume during these conversations are of great importance as they influence the level of mentees’ active engagement in analysing and reflecting on their practical experience. Hennissen et al. (2008) in an extensive literature review described a wide variety of mentors' practices that ranged from directive (such as assessing, advising, confirming and providing feedback) to non-directive (such as asking questions, developing alternatives, summarizing).

MERID is a two-dimensional model which incorporates two aspects of mentoring dialogues: the mentor’s style (degree of directiveness) and his/her initiative of introducing topics for conversation (degree of input). According to the MERID model, the aforementioned dimensions, the degree of mentor’s directiveness and the degree of initiation of topics for discussion define four distinct mentoring roles in the context of mentoring conversations, as shown in Fig. 3.5:

- the imperator, who introduces topics for discussion and uses directive skills to support his/her mentees,

- the initiator, who introduces topics for discussion but uses questions and other non-directive mentoring skills to address these topics,

- the advisor, who uses directive skills like instructions and advice to address the topics introduced by the mentee, and

- the encourager, who uses non-directive skills to elicit mentees’ opinions on the topics that the mentees themselves had originally introduced.

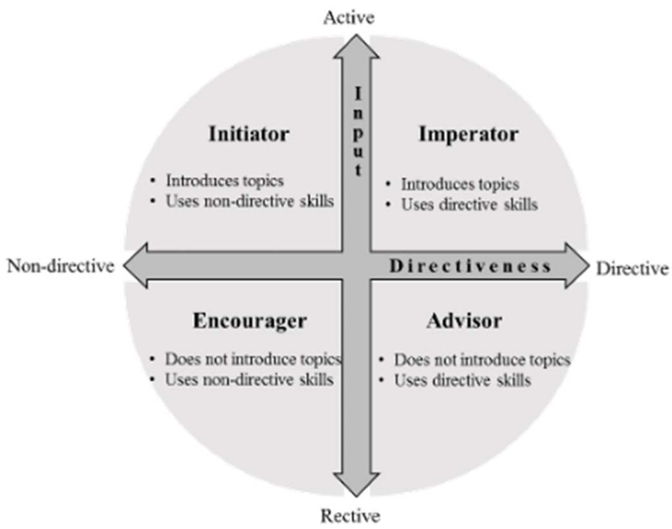


Fig. 3.5 The MERID model (Michailidi & Stavrou, 2021)

Mentors participate in the mentoring conversations with different roles, shifting their mentoring style in the course of mentoring meetings and among the discussed topics. Specifically, as mentees gain experience, mentors shift their mentoring style towards non-directive skills (e.g. from lesson modelers to encouragers). In fact one of the most significant and influential factors that determine the success of mentoring is the extent to which mentors' approach matches and is able to address mentees' learning needs (Michailidi & Stavrou, 2021).

The "Study and Research Paths for Teacher Education" (SRPs-TE)

As already said in the overview of the Pedagogical Model, another operational model used in CLIMADEMY has been developed by Barquero and Bosch (2015) within the paradigm established by the anthropological theory of the didactic (ATD) for mathematics education (Chevallard, 1992). The model is used to guide teachers in articulating their processes of co-learning, co-designing, and co-teaching in four phases, facilitated by a member of the hub who plays the role of facilitator.

One of the most important aspects in education, and in teacher training in particular, is the definition of the "role" that the learner – the trainee – is implicitly or explicitly asked to play. Trainee teachers are indeed both professionals, with their experience, knowledge and beliefs, and learners, within a formation path.

The IDENTITIES adaptation of the structure of the particular SRPs-TE consists of four types of activities (see table 3.1 and Fig.3.6). Each of them asks teachers (participants) to assume different roles.

Table 3.1 – Trainee teacher's possible roles (the icons are taken from the IDENTITIES project)

Type 1: **Trainee teacher as an *explorer***		In **Type 1** participants are asked to address initial questions, to share their knowledge and play the role of "*explorers*". This type of activity aims to break and ice and to have a first look to what exists, what emerges from and around them. In this type of activities all the participants are invited to share their knowledge, experiences, beliefs.
Type 2: **Trainee teacher as a *student***		In **Type 2** participants are asked to play the role of "*student*" or "*apprentice*". The main goal of this type of activity is to make participants get familiar with new contents or activities that could, to a certain extent, be also reproduced and used in an ordinary secondary classroom. This type of activity is supposed to convey novel knowledge or methods to the teachers.
Type 3: **Trainee teacher as an *analyst***		**Type 3** invites the participants to assume an external, "meta", position from which to analyse the materials and the activities they have experienced in the previous type. They are invited to change the role and adopt the role of "*analyst*". At this stage, educators introduce some tools/instruments to progress collectively with participants on the analysis of the materials.
Type 4: **Trainee teacher as a *designer***		**Type 4** consists of sharing some secondary school experiences with participants. Through the presentation of real case studies in secondary school, participants are expected to elaborate on how to use the tools to re-design and adapt the activity for their classes. They are invited to adopt the role of "*designer*".

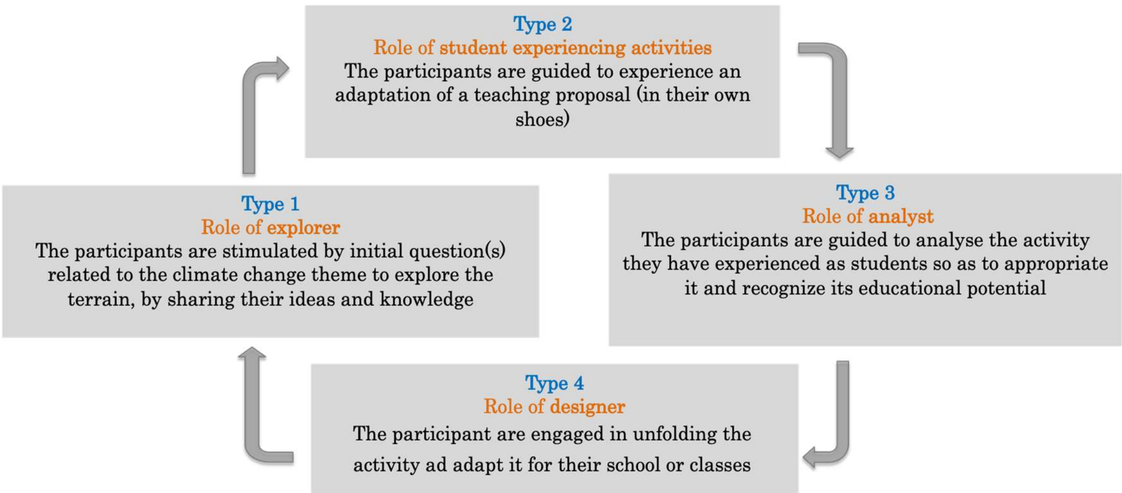


Fig. 3.6 Adaptation in submodules' structure of the SRP-TE
(adaptation from Barquero et al., 2018)

In the SRPs-TE model, the different types are supposed to constitute submodules to be carried out in sequence. In CLIMADEMY, this is recommended, the model is mainly used to make the role of the trainees explicit and guide the co-designers to construct the activities taking into account the multiple roles that teachers can and should play throughout their training (students, analysts, designers and implementers). The different roles also help to position the teachers differently with respect to knowledge.

C. *Relational and institutional dimensions: Recommendations to co-design and inhabit interdisciplinary contexts as boundary zones*

The interdisciplinary nature of Climate Change is a great challenge for teachers for different reasons. Our educational systems (from secondary school to university level) are still strongly based on disciplines.

Akkerman and Bakker (2011) propose a *meta-theory of boundary-crossing* that helps us understand why contact between different practices—disciplines, professions, organisations—can be such a powerful driver of learning. They define a **boundary** as any sociocultural discontinuity where distinct communities meet and must grapple with their differences. Boundaries do not simply separate; they also connect, acting as "in-between" spaces in which new meanings and relationships become possible. In today's poly-contextual world, students, researchers and workers routinely navigate several communities at once, so the capacity to learn *at* and *through* boundaries is increasingly central.

Akkerman and Bakker's meta-theory is rather widely important also in science and mathematics education to guide the design and inhabit of interdisciplinary contexts.

Akkerman and Bakker distinguish *boundary objects*—concepts or artefacts such as design sketches, protocols or data models that travel across practices and keep loosely shared meaning—from *boundary zones* or *encounters*, the conversational or material sites (joint workshops, interdisciplinary studios, hackathons, etc.) where people from different worlds negotiate discontinuities face-to-face. Boundary objects are defined as "objects that enact the boundary by addressing and articulating the multiple meanings and perspectives of various intersecting worlds" (ibid., p. 150). The nature of boundary objects is ambiguous; they enact the boundary by addressing and articulating meanings of various intersecting worlds (*both-and*), while they also move beyond the boundary since they have an unspecified quality of their own (*neither-nor*). This tension between the both-and and neither-nor nature of the boundary objects, and their intrinsic ambiguity activates a dialogue between disciplines and special learning potential.

Effective boundary work, they argue, is rarely a matter of simply translating one side's language into the other's; it is dialogical and recursive, often re-opening earlier questions of identity and purpose as collaboration deepens.

Within these zones they identify four learning mechanisms that capture the typical movements of dialogue across a boundary and that can actualise the learning potential at the boundary (Akkerman & Bakker, 2011) (see fig.3.7)

• **Identification** – actors (re)clarify who "we" and "you" are, making boundaries visible and sometimes renegotiating them.
• **Coordination** – they establish practical routines, translations or boundary objects that let collective activity flow despite differences.
• **Reflection** – the contrast between perspectives surfaces tacit assumptions; participants engage in deliberate perspective-making and perspective-taking.
• **Transformation** – the collaboration generates new, hybrid practices, objects or even identities that restructure both original worlds.

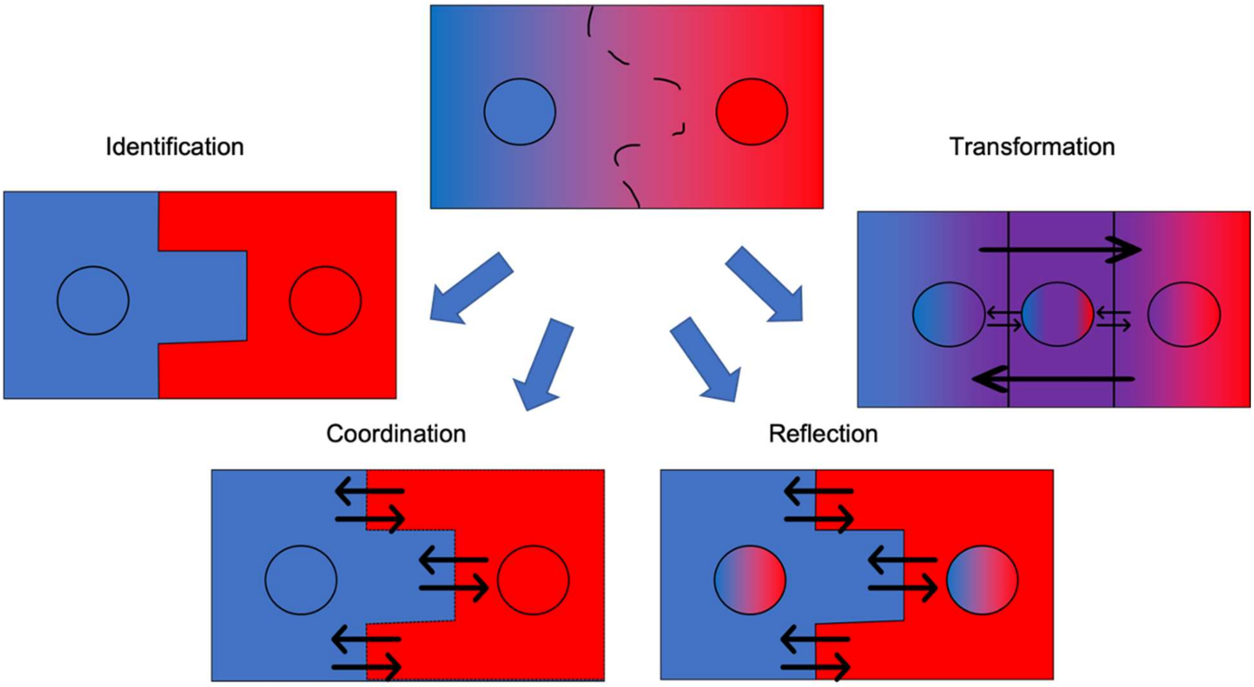


Fig. 3.7 Learning mechanisms at the boudnary
(picture by L. Miani, inspired by Akkerman and Bakker, 2011)

These mechanisms seldom unfold in a neat sequence; projects may loop, stall or skip stages, and questions of Identification often resurface after partial Transformation. Productive boundary-crossing tends to rely on brokers who straddle multiple communities, on boundary objects that remain "weakly structured" enough to invite multiple interpretations, on psychologically safe spaces and time for dialogue, and on a rough symmetry of power that legitimises every party's expertise.

For interdisciplinary design or analysis, the key implication is to treat the *interface itself* as a learning space. Rather than prematurely merging disciplines, programmes should deliberately construct boundary zones—shared labs, "third-space" courses, cross-disciplinary codebases—and scaffold them with activities that invite Identification, enable smooth Coordination, foster meta-level Reflection, and reward authentic Transformation. Practitioners can quickly diagnose where a collaboration sits by asking: What boundaries are currently felt? Which artefacts or routines are letting work flow? Where do participants explicitly compare viewpoints? And is anything genuinely new emerging and being institutionalised? In this way, Akkerman and Bakker's meta-theory supplies both a conceptual lens and a practical checklist for cultivating learning in the borderlands of modern knowledge work.

Below is an example of "question set" that teachers can keep at hand whenever they step into an interdisciplinary project or co-teaching arrangement. The prompts should be used flexibly—e.g., to open a planning meeting, to check in mid-project, or to steer a debrief with colleagues and students.

Identification – surfacing who we are and where the boundaries lie

• What boundary objects can we focus on?
• Which aspects of my own disciplinary identity do I feel most protective of—and why?
• When we talk about the "other" subject, what words or metaphors do we use?
• What counts as a good explanation or a convincing argument in each discipline represented here?
• Where do our curricular goals overlap, and where do they clearly diverge?
• Who is missing from this conversation, and how might their absence shape our boundaries?

Coordination – keeping joint activity moving despite differences
• What shared artefact (e.g., template, model, dataset, concept map) can serve as our "good-enough" reference point today?
• Which routines—timelines, feedback loops, division of labour—do we need to agree on right now so learners can progress?
• What translation work do we anticipate (terminology, notation, lab protocols), and who will broker it?
• Where might our classroom norms collide (e.g., discussion style, assessment timing), and how can we choreograph those moments?
• How will we let one another know, quickly, when a misunderstanding is blocking the flow?

Reflection – making tacit assumptions explicit through contrast and activating perspective making and taking
• What surprised me in the other discipline's approach, and what does that reveal about my own blind spots?
• If we videotaped this session, what "signature moves" of each discipline would be visible? Am I trying to take the perspective of the other discipline? Did I try to really grasp what can emerge from a different perspective?
• Which piece of feedback from the other teacher made me reconsider my practice?
• How can we script a short activity tomorrow that forces both disciplines to justify why they value certain evidence over others?

Transformation – co-creating genuinely hybrid practices or identities
• What new concept, tool, or routine has emerged that neither discipline owned outright yesterday?
• How might we formalise that emerging element so future classes can inherit it?
• Is there an assessment task we could design that cannot be completed without integrating both disciplinary lenses?
• What professional learning do we now need (together) because of the path we've opened?

• If we describe ourselves to colleagues next year, will we still say "physics teacher" and "history teacher," or something more fluid—and what would that label be?

D. Socio-cultural dimensions: CLIMADEMY competence framework as a reference to point out the general and specific goals to pursue through the activities

A fundamental element that must be considered in the analysis and design of teaching materials concerns the goals that the materials aim to achieve. In CLIMADEMY, following the EU competence frameworks, we use the definition of competence as "a set of knowledge, skills and attitudes" (e.g. Bianchi et al., 2022) and use this definition to frame the structure of the general and specific goals to pursue through the activities.

In CLIMADEMY we wished to develop a comprehensive framework directed to teachers and their practices in climate change education. We started our discussion on the competence framework from the analysis of the European sustainability competences, recently described in GreenComp framework (Bianchi et al., 2022) and developed as part of the European competence framework development.

In the GreenComp framework, four main areas of sustainability competences have been identified and each area includes three competences. The four areas with their respective competences are: 'Embodying sustainability values' (Valuing sustainability, Supporting fairness, Promoting nature); 'Embracing complexity in sustainability' (Systems thinking, Critical thinking, Problem framing); 'Envisioning sustainable futures' (Futures literacy, Adaptability, Exploratory thinking); and 'Acting for sustainability' (Political agency, Collective action, Individual initiative) (Bianchi et al., 2022).

Given the vast sustainability scope of the Greencomp framework, we considered to have more emphasis on climate change competences. Therefore, we also regarded the ClimComp research project (https://blogs.helsinki.fi/climatecompetencies/about/). The frameworks of ClimComp project are focusing namely on climate change competences needed in the society to mitigate climate change and adapt to the changes. The competences were studied both among young people and climate experts in Finland (Taurinen et al, 2024; Siponen et al, 2024). The climate change competency framework, built from young people's answers in a survey, consisted of six categories; CC systems change, CC science orientation, CC leadership, CC justice and collaboration, CC implementation, and CC well-being (Taurinen et al, 2024). These have been applied to the GreenComp model (Table 1) to form a CLIMADEMY framework, utilizable by teachers in school environments.

The CLIMADEMY framework for teacher climate education was designed by the University of Helsinki, by combining the GreenComp framework with the competence frameworks elaborated within the ClimComp research project. This framework was then co-developed and piloted with CLIMADEMY teachers. The result, illustrated in Fig.3.8, is a framework that brings concrete wordings and its tangibility is exemplified through learning outcomes, activities and assessment methods proposed.

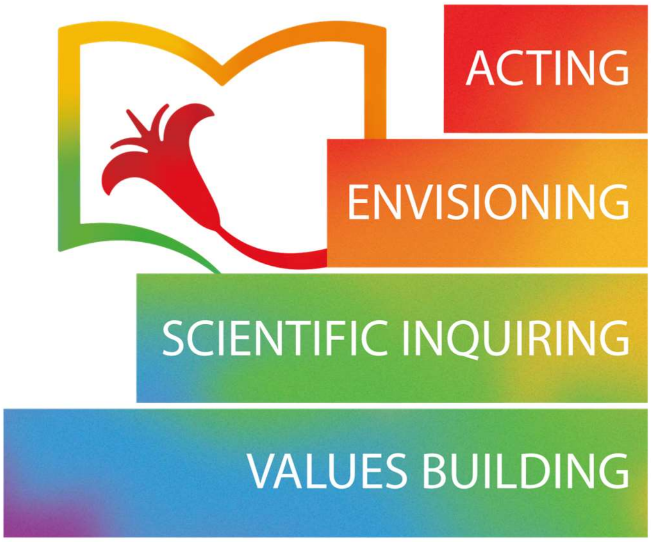


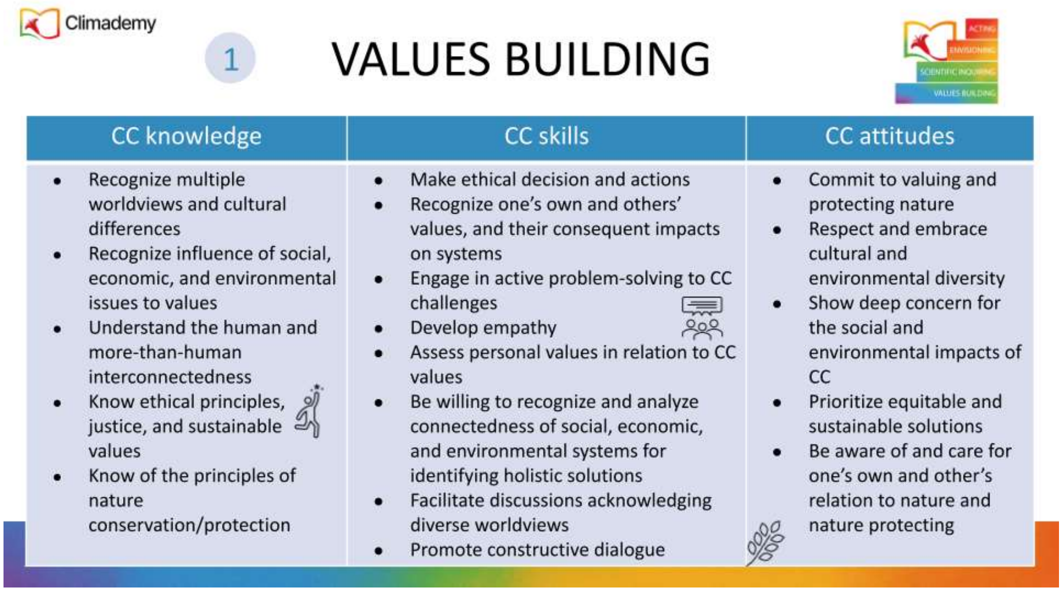
Fig. 3.8 CLIMADEMY competence framework – climate change competences for schools

The framework is articulated in four areas:

- *Values building*, to focus on the competences needed to recognise, apply, appreciate and live a shift toward values needed to promote sustainability;
- *Scientific inquiring* to focus on the scientific practices, such as embracing complexity, framing problems but also working with climate data and in acquiring climate related information from different sources of information;
- *Envisioning* to focus on the abilities to imagine new ways to frame the problems and search for solutions, imagining possible sustainable futures;
- *Acting* to bring competence to real life and articulate decisions at individual, collective and political.

For each CLIMADEMY competence area, the University of Helsinki researchers drafted the learning outcomes, the pedagogical methods and the assessment tools - based on the document elaborated by Thalia Tsaknia (EA), reported in Annex A, literature review and their experience in teaching climate change. The outcomes are reported in Fig. 3.9-12.

The articulation in the four areas stresses the extent to which climate change and its mitigation are transdisciplinary phenomena, and their understanding requires knowledge of science, technology, economics, social science, and psychology as well as related skills and values. For example, generating ideas related to reducing the amount of carbon dioxide in energy production and in the manufacturing of products, requires an understanding of issues related to society and the economy, in addition to science and technological knowledge. Moreover, associated values in this field relate to, for example, the environment, sustainability, and global justice. In addition to individual decisions, national-level decisions on measures such as legislation and taxation are needed. Even though such decisions are knowledge based, values and worldviews are the central drivers of the decisions.



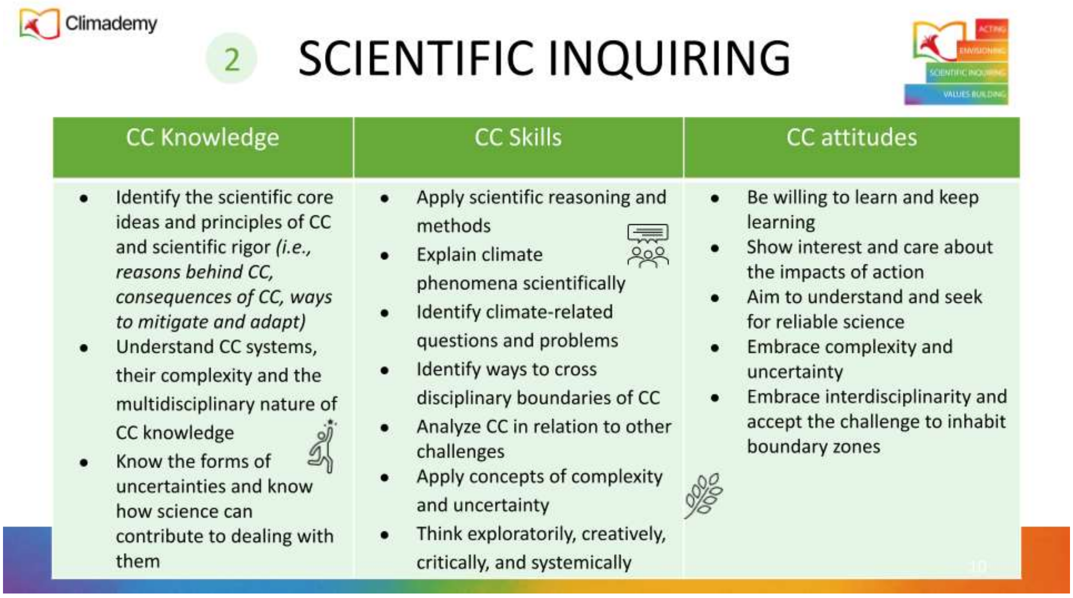
1 VALUES BUILDING

CC knowledge	CC skills	CC attitudes
• Recognize multiple worldviews and cultural differences • Recognize influence of social, economic, and environmental issues to values • Understand the human and more-than-human interconnectedness • Know ethical principles, justice, and sustainable values • Know of the principles of nature conservation/protection	• Make ethical decision and actions • Recognize one's own and others' values, and their consequent impacts on systems • Engage in active problem-solving to CC challenges • Develop empathy • Assess personal values in relation to CC values • Be willing to recognize and analyze connectedness of social, economic, and environmental systems for identifying holistic solutions • Facilitate discussions acknowledging diverse worldviews • Promote constructive dialogue	• Commit to valuing and protecting nature • Respect and embrace cultural and environmental diversity • Show deep concern for the social and environmental impacts of CC • Prioritize equitable and sustainable solutions • Be aware of and care for one's own and other's relation to nature and nature protecting

Fig. 3.9 Knowledge, skills, and attitudes of the Values Building competency in the CLIMADEMY competence framework

The core of comprehensive climate change competence is to build the foundation of values and motives. The competency of *Values building* (Fig. 3.9) is centred around the values and attitudes of oneself and others, and how these motivate action. The values are related to reasons of climate change, consequences, and actions. The students are encouraged to gain respect and care for the coexistence of people and the natural environment, considering ethical and justice principles.

Considering values and attitudes right from the start is seen as a base for building interest, motivation, and expertise on the topic of climate change. This competency brings together sustainability values, supporting fairness, need for collaboration and considering the interconnectedness of human and more-than-human. The *Values building* competency can be used as a base for learning outcomes related to engaging students with the topic of climate change and awakening their curiosity. Before loading new information, it is important to reason the knowledge and consider the question of 'why'. Transformative learning is one way to bring this step into action. It refers to the process of acquiring new knowledge/perspectives that significantly change an individual's beliefs, values, attitudes, and behaviors. *Values building* can be practised in school by encouraging students to reflection, dialogue, discussions and debates. For example, storytelling, role playing, and utopias can be utilized as tools. Assessment can be based on learning diaries or the teacher observing the reflections students make, among others.



CC Knowledge	CC Skills	CC attitudes
• Identify the scientific core ideas and principles of CC and scientific rigor *(i.e., reasons behind CC, consequences of CC, ways to mitigate and adapt)* • Understand CC systems, their complexity and the multidisciplinary nature of CC knowledge • Know the forms of uncertainties and know how science can contribute to dealing with them	• Apply scientific reasoning and methods • Explain climate phenomena scientifically • Identify climate-related questions and problems • Identify ways to cross disciplinary boundaries of CC • Analyze CC in relation to other challenges • Apply concepts of complexity and uncertainty • Think exploratorily, creatively, critically, and systemically	• Be willing to learn and keep learning • Show interest and care about the impacts of action • Aim to understand and seek for reliable science • Embrace complexity and uncertainty • Embrace interdisciplinarity and accept the challenge to inhabit boundary zones

Fig. 3.10 Knowledge, skills, and attitudes of the *Scientific inquiring* competency in the CLIMADEMY competence framework

Scientific inquiring builds the basic understanding of climate change as a scientific phenomenon (Fig. 3.10). Scientific tools such as critical thinking, systems thinking and problem framing are needed to get a big picture and coherent understanding of causalities related to climate change. This can be reached by traditional learning methods, like independent study and inquiry, but also collaborative learning activities, like group work and project-based learning. Learning can be assessed with tests and examinations, but also discussions, portfolios, concept-mapping or by evaluation of artefacts (for example, report, video, exhibition).

The competencies emphasize the use of knowledge in different situations. Therefore, it is relevant to describe what is essential knowledge in the context of climate change. Although climate change is a multidisciplinary topic by nature, we list here the scientific knowledge or core ideas in this field:

- Climate science knowledge:
  - conservation of energy (first law of thermodynamics), direction of phenomena, heat transfer (second law of thermodynamics)
  - how climate system works and what are interactions in the system
  - influence of greenhouse gases and aerosols to climate and origins of them
  - how production of energy, materials and objects and traffic influences climate and water cycles mechanism
  - reasons and causes of climate change
  - strategies for climate change mitigation and adaptation in different levels: personal – local – global
  - economic, social science, psychology views to climate change mitigation
- Knowledge about climate research and outcomes:
  - nature of climate research and origins of climate related knowledge
  - nature of climate knowledge and models

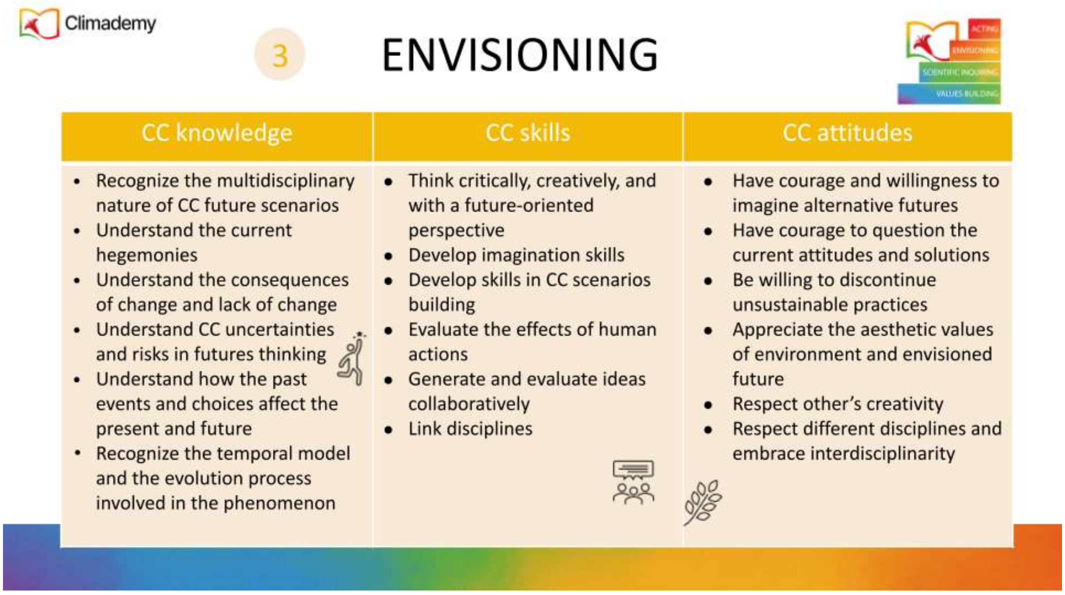


Fig. 3.11 Knowledge, skills, and attitudes of the *Envisioning* competency in CLIMADEMY competence framework

Envisioning competency embraces students' creativity and ideas of the future (Fig. 3.11). It revolves around envisioning life and solutions considering climate change, with the ability to explore, imagine, and generate ideas. These ideas can be about challenging the status quo, creating new solutions, or imagining future perspectives, while utilizing systems and artistic thinking. *Envisioning* competency calls out for limitless imagination, where utopias are welcomed.

The GreenComp and ClimComp competence frameworks applied here are considering the futures literacy, adaptability, exploratory thinking and leadership. In our framework, leadership is represented by the orientation to find solutions and being courageous and bold in creating ideas in collaboration with others. The learning outcomes based on the *Envisioning* competency are about willingness to use CC knowledge and build new ideas on top of it and to identify climate change related challenges and evaluate new solutions. In practice, activities that include art-based methods are especially suitable for developing the competency of *Envisioning* as these methods support free and creative outcomes and ways of executing.

Climademy

4 ACTING

CC Knowledge	CC Skills	CC attitudes
• Define and prioritize CC mitigation and adaptation • Identify the relevant policies and stakeholders to address CC issues • Understand the structures within the society, its functionalities and capabilities	• Implement CC actions considering: possible future scenarios, different stakeholders, sustainability dimensions (environmental, social, economic) and context • Engage in active problem solving to address CC challenges • Work collaboratively • Enable mitigation and adaptation action • Communicate and articulate directions effectively • Think globally and locally	• Be willing to act in line with CC values • Have courage to change • Take accountability and demand for political accountability • Aim for action that is just and equal • Commit to facing the challenges and opportunities of CC • Be willing to engage with others • Appreciate global and local perspectives • Act with empathy and sensitivity

Fig. 3.12 Knowledge, skills, and attitudes of the *Acting* competency in the CLIMADEMY competence framework

Acting competency (Fig. 3.12) is about bringing plans into action, building on a strong value-base, scientific understanding of climate change and creativity to design new solutions. Acting competency includes critically designing, selecting, and conducting concrete actions that are aimed at solving climate change-related problems. Collaborative skills are especially important within this competency, as the planning and doing needs to happen in an equal and democratic way.

Learning outcomes derived from the *Acting* competency include understanding of and engagement in political agency as well as your own potential and well-being. This can be practised in schools, for example, via project-based learning and community projects in collaboration with the society. Activism is one way to develop the *Acting* competency as it fosters the sense of accomplishment and hope to deal with CC issues. It is important to enable hands-on practices for the students to achieve concrete outcomes.

In the teacher training activities of the CLIMADEMY hubs, these tables are suggested to be used, together with the check list resulting from MER and CoRe, to brainstorm and share the general and specific goals of the activities.

The assessment tools for sustainability competencies are described in Section 3.5 and in Annex B. There, we introduce approaches and tools for assessing students' key-climate competences and for assessment of students' learning process. The authors of the document recommend that versatile diagnostic, formative, summative, self and peer assessment practices are essential part of climate change education. These practices support and supplement each other. Furthermore, the teacher's role as a part of assessment practices is analysed and examples of the assessment practices are introduced and discussed.

E. Assessment guidelines

Rationale behind Assessment

When assessment is discussed in educational contexts, including teacher training, it is always very important to highlight that the concept of assessment refers to the actions which are supportive to the learning process and the actions which are aimed at determining the amount and quality of the learning outcome (Black & Wiliam, 2009). Thus, assessment is a much wider concept than "grading": assessment also includes actions that provide feedback for the students and information for the teacher about the students' learning process, without the need to assign grades to the students. In this context, assessment is related to the aims of the climate education lesson or a larger climate education module or even on climate education competence framework. In this framework, as already stressed, values and attitudes are seen as the foundation of climate change competence of the youth. Scientific knowledge and ability to search new information on climate change is the basic competence in the framework. Creativity and ability to design new solutions is needed to build sustainable futures. Action competence brings competence to real life.

When an assessment action makes a judgement or grade of the performance of a student, the type of assessment is summative (Wiliam, 2000). While supporting the learning process, the type of assessment is formative. These two main types of assessment require individual or collective interpretation of the aims for teaching and learning.

In an assessment action, the focus is always on both the quality of the learning process (the formative type of assessment) and the learning outcome (the summative type of assessment) with a focus on improving students' learning process and outcomes. Therefore, both the teacher and the students use assessment data for developing teaching and learning. This type of assessment is called enhancement-led assessment (Patton, 2011; Atjonen, 2015). Consequently, it is important to support students in using assessment feedback in the development of their learning process and learning outcome. Therefore, simple testing has limitations in supporting the learning of climate competences in a versatile way (OECD, 2020).

The assessment actions are always based on the verified evidence and the grading is done according to the criteria or a rubric. A rubric is a tool, which helps in assessing students' learning outcomes or an artefact created during the learning process. A rubric usually includes three essential features: evaluative criteria, quality definitions of the criteria at particular levels, and a scoring strategy (Dawson, 2007).

Assessment in the context of climate education could be challenging for many reasons. First, the aims for climate education are set holistically or the climate competence framework is complex. For example, a teacher could support students to acquire at the same time several competences, such as, climate values, core knowledge in the domain and skills needed in generating alternatives. Consequently, a teacher should assess the achievement of several aims at the same time. Second, the assessment of the learning process could be challenging because of the several activities students are guided to engage in. For example, a teacher can guide students to collaborate and engage in scientific and engineering knowledge practices and, moreover, ask them to construct an educational artefact, such as a poster or a report. Knowledge practices refer to practices that are similar to climate researchers or designers, such as asking questions, defining problems, planning, and carrying out investigations, analysing and interpreting data, developing, and using models, generating alternatives or solutions and communicating information (Krajcik & Czerniak, 2013). Third, the created artefacts could also be assessed, not only the learning outcomes and process. To be considered as an artefact, it needs to be lasting, durable, public and materially present (Frederik, 2011). Moreover, aesthetic aims, such as exceptionality and diversity, ethical aims and aims related to sustainability, are often emphasized as aims for the artefact.

In the previous paragraph, it was mentioned that the aims for climate education are often set holistically. This means that in addition to climate education aims, also aims for learning transversal competencies (also called key competencies, generic competencies, or 21st century competencies) are set for a lesson or study module. For example, creative and critical thinking skills, collaboration and problem-solving skills, skills needed in the use of various tools, such as digital and manual tools are considered as transversal competencies (Voogt & Roblin, 2012). Therefore, aims related to the transversal competencies form a group of aims which could be assessed as a part of climate learning (Pepper, 2011). However, the aims related to the transversal competencies are often not shared with the students (Scott & Yates, 2002). Therefore, self-assessment and peer-assessment that move learners forward do not necessarily focus enough on the learning of transversal competencies.

The assessment and the feedback affect how the students learn, collaborate, and change their behavior (Weeden et al. 2002). Assessment with encouragement supports the student's self-concept as a responsible citizen. This type of encouragement and constructive feedback is supportive in the development of students' self-efficacy, in other words their belief in their capacity to execute behaviors necessary to the use their knowledge and creativity (Bandura, 1997). Self-efficacy reflects confidence in the ability to exert control over one's own motivation, behavior, and social environment. Climate change mitigation on an individual level does not depend only on opportunities for action but also on one's self-awareness and self-efficacy (Bianchi et al., 2022). Mitigation has a strong attitudinal aspect – the willingness to act.

Encouragement and constructive feedback could improve students' growth or mindset (Nadelson, 2021). Therefore, the assessment actions should indeed be constructive and encouraging during the lesson or larger climate module. However, the students need to understand the feedback and according to that, direct their learning and behavior in the desired direction. The feedback is directed and connected to each student's actions and outputs. The students are directed simultaneously to interpret feedback so that it will be easier for them to change their own way of behavior.

Quality Assessment

The quality of assessment depends on the characteristics of assessment, such as validity, reliability, objectivity and authenticity. According to the validity characteristics, the assessment should focus on the attitudes, values, knowledge and skills or competencies that are aimed at climate education. In the context of this document, the assessment should focus on essential and relevant issues, described in the climate competence framework. Thus, the starting point for the assessment should be the competence framework. Moreover, the assessment should be open and transparent, and the participants must know the competence framework, including aims for learning transversal competencies, and the assessment practices planned to be used. Therefore, it is important to pay attention to the aims of the lesson or the teaching module and the expected learning outcomes: students and teachers should share the same aims. After sharing the aims, assessment practices to be used should be agreed. In practice, the students should be invited to be involved in the planning of the lesson or module and planning its assessment (McAlpine, 2002; McMillan, 2013).

The demand for the reliability of the assessment includes the fact that the assessment tools could be interpreted in a similar way and assessment practices do not contain random errors and that every student is given feedback and support according to their needs and process and product are assessed according to the agreed criteria in the same way. The objectivity of the assessment includes the fact that the effect of the subjective factors, values and preconceptions have been removed (McAlpine, 2002; McMillan, 2013).

The authenticity of assessment refers to the practices used in assessment. The practices should be in line with the pedagogical approaches and learning environments used. Authenticity refers also to the next-stage studies and competences needed in adult life.

Assessment Types and Methods

Diagnostic, formative and summative types of assessment are main types of assessment (see Fig. 3.13). The aim of diagnostic assessment is to determine what the student already knows before teaching. Diagnostic tests, asking questions and observations are tools for diagnostic assessment. Formative assessment provides feedback on learning-in-process and steer the process towards goals. Formative test, questioning and observing, self-assessment forms are used for tools in formative assessment. Summative assessment is used at the end of the learning process for evaluating students' learning against the competence framework. Therefore, it sums up and predicts the performance in future studies after the learning process. Well planned summative exams or tests or use of concept maps could be used for summative assessment (McAlpine, 2002; McMillan, 2013).

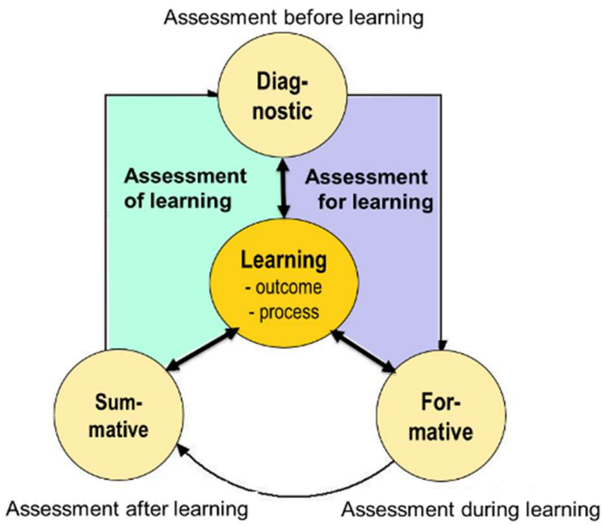


Fig. 3.13 Main types of assessment

Assessment could be formal or informal (fig. 3.14). Formal assessment is the systematic where tests or other tools that measure what and how well the students have learned are used. Formal assessments determine the students' proficiency or mastery of the content and can be used for comparisons against competence framework or curriculum aims. Examples of formal assessment are standardized tests or systematic use of student assignments. Informal assessments are spontaneous and could be easily incorporated in day-to-day classroom activities. Informal assessments are content and performance driven. Examples of informal assessment are checklist, observation, and questioning. (McAlpine, 2002; McMillan, 2013),

	Formative Assessment	Summative Assessment
Informal	Questioning Feedback Peer assessment Self-assessment	Essays in uncontrolled conditions Portfolios Coursework Teacher assessment
Formal	Further analysis or tests, exams, essays Target setting	Tests Exams Essays in controlled conditions

Fig. 3.14. Purposes and tools for assessment

Finally, we can mention that there are several other views to assessment. For example, assessment could be teacher or student directed. If assessment is student-directed activity it is called student self-assessment. (McAlpine, 2002; McMillan, 2013).
In Annex B, a more detailed description of exemplar tools for diagnostic, formative assessment is reported. It can be used with the teachers to spark their imagination and make aware instruction design.

The key message that we suggest is that both formative and summative assessment are needed, and they can be realized also through self- and peer assessment practices in climate education. Both types of assessment are carried out according to the holistic aims, objectives or learning outcomes descriptions. Formative assessment supports students learning during the process. Summative assessment summarizes the student's learning outcomes. Therefore, it is more than grading and a single grade might not be enough for summarizing. In this document alternative assessment tools, such as self-assessment, use of portfolio and assessment of artefacts. The use of the portfolio method or construction and assessing of artefacts enables both the short- and long-term tracking of learning activities and thus gathers the evidence for assessing the process and finally assess summatively the reached level.

4. CLIMADEMY Template for teacher training activities and prototypes of activities

4.1 CLIMADEMY template to co-design activities in coherence with the pedagogical model.

In this section we report the schematic structure of a possible CLIMADEMY activity for teacher training that implements the pedagogical model. The template can be downloaded here.

General Information	
Title of activity:	
Estimated duration:	
Grade:	
Related disciplines:	

Contextual Information	
Reference to the hub:	
Author(s) of the activity:	
Schools/contexts where the activity was developed:	
Schools/contexts where the activity was implemented:	

Topic of Activity	
Fundamental scientific ideas of Climate Change	

Interconnection with national Hub *(if applicable)*	

Values Building Objectives	
*Please select the **knowledge** objectives covered in the activity*	• Recognize multiple worldviews and cultural differences • Recognize the influence of social, economic, and environmental issues to values • Recognize the human and more-than-human interconnectedness • Know ethical principles, justice, and sustainable values • Know principles of nature conservation/protection • Recognize the meaning and the value of the perspective of complexity to think and act for sustainability • Other:
*Please select the **skills** objectives covered in the activity*	• Make ethical decisions and take action • Recognize one's own and others' values, and their consequent impacts on systems • Develop empathy • Assess personal values in relation to climate values • Be willing to recognize and analyze the connectedness of social, economic, and environmental systems to identify holistic solutions • Facilitate discussions acknowledging diverse worldviews • Promote constructive dialogue • Other:
*Please select the **attitudinal** objectives covered in the activity*	• Commit to valuing and protecting nature • Respect and embrace cultural and environmental diversity • Show deep concern for the social and environmental impacts of climate change • Prioritize equitable and sustainable solutions • Be aware of and care for one's own and others' relationship with nature and its protection • Other:

Scientific Inquiring Objectives

*Please select the **knowledge** objectives covered in the activity*	• Identify the scientific core ideas and principles of CC and scientific rigor • Understand CC impacts and its sources • Understand the multidisciplinary nature of CC knowledge • Analyze the interactions within climate systems to identify factors contributing to their complexity • Know the scientific core ideas and principles of the science of complex systems, with a special emphasis of their role in CC • Know the forms of uncertainties involved in CC, (for example, by distinguishing between epistemic, ontic and aleatoric, and reflexive uncertainty) and know how science can contribute to dealing with them • Other:
*Please select the **skills** objectives covered in the activity*	• Apply scientific reasoning and methods • Explain climate phenomena scientifically • Identify climate-related questions and problems • Identify the disciplinary knowledge and skills involved in dealing with a CC problem and the need to cross disciplinary boundaries Analyze climate change in relation to other challenges • Apply concepts of the science of complexity to frame CC problems • Think exploratorily, creatively, critically, and systemically • Other:
*Please select the **attitudinal** objectives covered in the activity*	• Be willing to learn and keep learning • Show interest in and care about the impacts of action • Aim to understand and seek reliable science • Embrace complexity and uncertainty • Embrace interdisciplinarity and accept the challenge to inhabit boundary zones • Other:

Envisioning Objectives	
*Please select the **knowledge** objectives covered in the activity*	• Recognize the multidisciplinary nature of CC future scenarios • Understand the current hegemonies • Understand the consequences of change and lack of change • Understand CC uncertainties and risks in futures thinking • Understand how the past events and choices affect the present and future • Recognize the temporal model and the evolution process involved in the phenomenon • Other:
*Please select the **skills** objectives covered in the activity*	• Think critically, creatively, and with a future-oriented perspective • Develop imagination skills • Develop skills in CC scenarios building • Evaluate the effects of human actions • Generate and evaluate ideas collaboratively • Link disciplines • Other:
*Please select the **attitudinal** objectives covered in the activity*	• Have the courage and willingness to imagine alternative futures • Have the courage to question current attitudes and solutions • Be willing to discontinue unsustainable practices • Appreciate the aesthetic values of the environment and envisioned future • Respect others' creativity Respect different disciplines and embrace interdisciplinarity • Other:

Acting Objectives	
*Please select the **knowledge** objectives covered in the activity*	• Define and prioritize CC mitigation and adaptation • Identify the relevant policies and stakeholders to address CC issues • Understand the structures within the society, its functionalities and capabilities • Other:

*Please select the **skills** objectives covered in the activity*	• Implement CC actions considering possible future scenarios • Implement CC actions considering different stakeholders • Implement CC actions considering the different dimensions of sustainability (environmental, social, economic) • Engage in active problem-solving to address climate change challenges • Work collaboratively • Enable mitigation and adaptation action • Articulate directions effectively • Communicate effectively • Think globally and locally • Consider the context and environment when taking action • Other:
*Please select the **attitudinal** objectives covered in the activity*	• Be willing to act in line with environmental, social and economic values • Have the courage to change • Take accountability and demand political accountability • Aim for action that is just and equal • Commit to facing the challenges and opportunities of climate change • Be willing to engage with others • Appreciate global and local perspectives Act with empathy and sensitivity • Other:

Assessment of learning outcomes	
Please describe how the -Climate Change **Values Building** learning outcomes are assessed	
Please describe how a **Scientific Inquiring** learning outcomes are assessed	
Please describe how **Envisioning** learning outcomes are assessed	
Please describe how **Acting** outcomes are assessed	

Detailed description of the activity
Brief description *(provide a description of the activity that could help other teachers to do the activity)* **Realisation of the experience** ***Material:*** *(provide a description of the materials needed)* ***Procedure:*** *(provide a description of the procedure)*

Worksheets
Please provide any worksheets or other kind of supporting material developed

Tips for designing the activity and its evaluation

Start-up the process and establishment of the management and coordination structure

Start-up phase (management and coordination)
Organization of a calendar of informal meetings (if needed, *with the support of an external stakeholder expert in project design and in science education*) in order to:

- (relational level) identity the group of teachers who will be part of the project; outline the management and coordination structure (establish, in the group of teachers, who can play the role of coordinator, facilitator, implementer…); map teachers' motivations, interests and areas of disciplinary comfort zones; identify the needs for eventual external resource;
- (epistemic-cognitive level) map preliminary ideas about the topics, the disciplinary knowledge involved, the knowledge present in the group and the knowledge that has to be developed or imported (in terms of experts that can provide an external support);
- (institutional level) map possible contexts (curricular, extra-curricular, spaces …) and possible institutional barriers that should be addressed
- (socio-cultural level) share reasons why students should be involved in the activity/project and why the school should invest time and personnel resources on the project.

Study of existing materials

Organization of the "scientific" agenda (if needed, *with the support of an external stakeholder expert in project design and in science education*) to select materials and organize a process of studying. This phase can be done individually or in group. In the latter case, it should include both moments of personal study and moments of co-learning. Suggestions for this phase are:

- (relational level) to select scientific and educational materials;
- (epistemic-cognitive level) to study the materials to develop disciplinary, inter-disciplinary knowledge, but also to develop knowledge on science education research on students' difficulties.
- (socio-cultural level) to address, systematically, questions about what CLIMADEMY competences the activities intend to develop and build a strategy on how to pursue them with the activity.

Analysis of the activity

Organization of the "scientific" agenda (if needed, *with the support of an external stakeholder expert in project design and in science education*) to analyse the materials. This phase can be carried out in parallel to the previous one. It should include both moments of personal work and moments of co-learning. Suggestions for this phase are:

- (relational level) to build interdisciplinary workshops to create a safe boundary safety, where different competences are coordinated to analyse the materials, identify eventual boundary objects and analyse them;
- (epistemic-cognitive level) to organize individual or in-group moments aimed to deeply analyse the materials, unpack their educational potential (for this phase, follow the guidelines of Section 3.3- A);
- (socio-cultural level) to organize individual or in-group moments to analyse the contribution of the activities to the development of CLIMADEMY competences.

Design of the activity and content creation

Draft the activity, by:
(epistemic-cognitive level) implementing the suggestions from MER and CoRE; define the assessment tools (Section 3.3 – A; Section 3.3 – E; Annex B);
(relational level) taking care of the interdisciplinary dynamics among teachers (Section 3.3 – C);
(pedagogical level) choosing the learning environment and the forms of participation you intend to create (Section 3.3 – B);
(socio-cultural level) point out learning outcomes in coherence with CLIMADEMY competence framework (Section 3.3 – D; Annex A).
Implement the activity by taking note of the difficulties, the criticalities and the potential at epistemic-cognitive, relational, pedagogical, socio-cultural and institutional level.

A posteriori reflections on the activity and re-design

Analyse the activity carried out along the various levels.
Examples of questions to guide the reasoning:
- Did the activity meet the expectations? If not, what happened that was not expected?
- Why was it important for the students to do this activity?
- What competences did this activity develop?
- Were any difficulties encountered by the students and/or teachers? if so, which ones?
- What was learned?
- How was the dynamics among the teachers?
- Did the activity meet any difficulty at institutional level?
- Did the activity have any implication at institutional level?

Redesigning the activity
Examples of questions to guide reasoning:
What changes would you make to the activity?

5. Conclusions

The deliverable D3.2 reflects the work conducted in the frame of WP3, tasks 3.1 and 3.2. The model has been built through a collaborative process among the partners and the other WPs. In particular, educational materials (WP2) have been revised or developed according to the educational model from WP3 and transformed into prototypes of teaching activities for teacher education. These activities have been implemented in the CLIMADEMY network established in WP4 and in the training activities of WP5. They provided new insights to revise and improve the WP3 model.

After three years refining our CLIMADEMY model, one conclusion is particularly clear: climate change is forcing education—teacher preparation included—to reinvent itself. Tackling the crisis demands that schools abandon rigid subject silos and adopt an interdisciplinary, ecosystem-level view that unites science with social, economic, political and technological insights. This overhaul is not just for students; educators must rethink what they know, the skills they cultivate and the attitudes they model.

Yet climate instruction is hard precisely because it straddles so many fields. While the science (physics) of greenhouse warming is somehow straightforward, meaningful mitigation hinges on competencies that cross natural sciences, engineering, economics, and social sciences and on dispositions such as critical and creative thinking, sustainable values and socio-emotional awareness. CLIMADEMY was designed to guide teachers in weighing research-based resources and in balancing epistemic-cognitive, pedagogical, relational, institutional and cultural dimensions of their practice.

The deeper obstacle lies in science education's Newtonian heritage—deterministic, linear and reductionist—ill-suited to the emergent, non-linear dynamics of Earth systems. Fostering “sustainability competences” therefore calls for an epistemic shift: classical mechanics must be taught not as the universal key to nature, but as one lens among many, complemented by thermodynamics, chaos, quantum and network theories that better capture real-world complexity and uncertainty.

In short, we must ask, as one CLIMADEMY teacher did: “How much Newton should we still teach?” The goal is not to discard Newton, but to place him in a richer, humbler narrative—one that equips learners to navigate uncertainty and engage intelligently with the intertwined challenges of the Anthropocene.

References

Developing the pedagogical model

Akkerman, S. F., & Bakker, A. (2011). Boundary crossing and boundary objects. *Review of Educational Research, 81*(2), 132–169.

Avalos, B. (2011). Teacher professional development in teaching and teacher education over ten years. Teaching and Teacher Education, 27(1), 10–20. https://doi.org/10.1016/j.tate.2010.08.007

Barquero, B., & Bosch, M. (2015). Didactic engineering as a research methodology: From fundamental situations to study and research paths. In A. Watson & M. Ohtani (Eds.), *Task Design in Mathematics Education* (pp. 249–272). Springer.

Barquero, B., Bosch, M., & Romo, A. (2018). Mathematical modelling in teacher education: Dealing with institutional constraints. ZDM, 50(1-2), 31–43. https://doi.org/10.1007/s11858-017-0907-z

Bianchi, G., Pisiotis, U., Cabrera Giraldez, M. (2022). *GreenComp – The European sustainability competence framework*. Publications Office of the European Union, Luxembourg. https://doi.org/10.2760/13286, JRC128040.

Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability (formerly: Journal of Personnel Evaluation in Education)*, *21*(1), 5-31.

Bosch, M. (2018). Study and Research Paths: a model for inquiry. International Congress of Mathematicians, World Scientific Publishing Co. Pte. Ltd., Rio de Janeiro, 4001-4022.

Bradbury, L. (2010). Educative mentoring: Promoting reform-based science teaching through mentoring relationships. Science Education, 94(6), 1049-1071.

Branchetti, L., & Levrini, O. (accepted). Critical Encounters with Interdisciplinarity in Mathematics Pre-Service Teacher Education, *Recherche en Didactique des Mathématiques*

Chevallard, Y. (1992). Fundamental concepts in didactics: Perspectives provided by an anthropological approach. In *Research in Didactique of Mathematics: Selected Papers* (pp. 131–168).

Braun, V., & Clarke, V. (2024). Thematic analysis. In *Encyclopedia of Quality of Life and Well-Being Research* (pp. 7187–7193). Springer.

Chevallard, Y. (1992). Fundamental concepts in didactics: Perspectives provided by ananthropological approach. In: Douady R, Mercier A (eds) Research in Didactique of Mathematics. Selected Papers. La Pensée sauvage, Grenoble, France, pp 131-167.

Chevallard, Y. (2002). Organiser l’étude. 3. Écologie & régulation. Actes de la XIe école d’été de didactique des mathématiques (pp. 41-56). Grenoble: La Pensée Sauvage.

Chevallard, Y. (2015). Teaching mathematics in tomorrow’s society: A case for an oncoming counter paradigm. In S.J. Cho (Ed.), Proceedings of the 12th international congress on Mathematical Education (pp. 173–187). Berlin: Springer.

Dawson, P. (2017) Assessment rubrics: towards clearer and more replicable design, research and practice. *Assessment & Evaluation in Higher Education, 42*(3), 347-360.

Duit, R., Gropengießer, H., Kattmann, U., Komorek, M., & Parchmann, I. (2012). The Model of Educational Reconstruction – A framework for improving teaching and learning science. In D. Jorde & J. Dillon (Eds.), *The World of Science Education: Science Education Research and Practice in Europe* (pp.13-37). Rotterdam: Sense Publishers.

European Parliament. (2019). *European Parliament resolution of 28 March 2019 on climate change* (2018/0179). https://www.europarl.europa.eu/doceo/document/TA-8-2019-0217_EN.html

Favier, T., Van Gorp, B., Cyvin, J.B., & Cyvin, J. (2021) Learning to teach climate change: students in teacher training and their progression in pedagogical content knowledge, Journal of Geography in Higher Education, 45:4, 594-620. https://doi.org/10.1080/03098265.2021.1900080

Frederik, I., Sonneveld, W. & de Vries, M.J. (2011). Teaching and learning the nature of technical artifacts. *International Journal of Technology and Design Education, 21*, 277–290. https://doi.org/10.1007/s10798-010-9119-3

Funtowicz, S. O., & Ravetz, J. R. (1993). Science for the post-normal age. *Futures, 25*(7), 739–755.

Garet. M., Porter. A., Desimone, L., Birman, B. &Yoon, K.S. (2001). What makes professional development effective? Results from a national sample of teachers. American Education Research Journal, 38(4), 915–945. https://10.3102/00028312038004915

Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK In A. Berry, P. Friedrichsen, & J. Loughran (Eds.), *Re-examining Pedagogical Content Knowledge in Science Education* (pp. 38–52). Routledge.

Hennissen, P., Crasborn, F., Brouwer, N., Korthagen, F., & Bergen, T. (2008). Mapping mentor teachers' roles in mentoring dialogues. Educational research review, 3(2), 168-186.

Hestness, E., McGinnis, J.R. & Breslyn, W. (2015). Integrating Sustainability into Science Teacher Education Through a Focus on Climate Change. In S.K. Stratton et al. (eds.), *Educating Science Teachers for Sustainability*, ASTE Series in Science Education (pp. 143-162). Springer. https://doi.org/10.1007/978-3-319-16411-3_9

Hiebert, J., Gallimore, R., & Stigler, J. (2002). A knowledge base for the teaching profession: What would it look like and how can we get one? Educational Researcher, 31(5), 3–15. https://doi.org/10.3102/0013189X031005003

Hinesjeffrey, P. J., McCartneyand, M., & Wible, B. (2013). Plenty of challenges for all. *Science, 340*(6130), 290–291.

Incropera, F. P. (2015). *Climate change: A wicked problem—Complexity and uncertainty at the intersection of science, economics, politics and human behaviour*. Cambridge University Press.

Jorgenson, S.N., Stephens, J.C., & White, B. (2019). Environmental education in transition: A critical review of recent research on climate change and energy education, *The Journal of Environmental Education*, 50(3), 160-171. https://doi.org/10.1080/00958964.2019.1604478

Kitchen, J., & Figg, C. (2011). Establishing and sustaining teacher educator professional development in a self-study community of practice: Pre-tenure teacher educators developing professionally. *Teaching and Teacher Education*, 27(5), 880–890. https://doi.org/10.1016/j.tate.2011.02.003

Koffeman, A. & Snoek, M. (2019) Identifying context factors as a source for teacher professional learning, *Professional Development in Education*, 45(3), 456-471, https://10.1080/19415257.2018.1557239

Krajcik, J. S., & Czerniak, C. M. (2013). *Teaching science in elementary and middle school: A project-based approach*. Taylor and Francis.

Kulgemeyer, C., & Riese, J. (2018). From professional knowledge to professional performance: The impact of CK and PCK on teaching quality. *Journal of Research in Science Teaching, 55*, 1393–1418. https://doi.org/10.1002/tea.21457

Kumar, S., Darshna, A., & Ranjan, D. (2023). A review of literature on the integration of green energy and circular economy. *Heliyon, 9*, Article e12345.

Levrini, O., Pietrocola, M., & Erduran, S. (2024). Breaking free from Laplace's chains: Reimagining science education beyond determinism. *Science & Education, 33*(3), 489–494.

Levrini, O., Tasquier, G., Barelli, E., Laherto, A., Palmgren, E., Branchetti, L., & Wilson, C. (2021). Recognition and operationalisation of future-scaffolding skills. *Science Education, 105*(2), 281–308.

Levrini, O., Tasquier, G., Branchetti, L., & Barelli, E. (2019). Developing future-scaffolding skills through science education. *International Journal of Science Education, 41*(18), 2647–2674.

Levrini, O., Tasquier, G., D'Orto, E., Miani, L., Rossi, C., Satanassi, S., Stavrou, D., Michailidi, E., Metaxas, I., Riuttanen, L., Lavonen, J., Lauri, A., Lintuvaara, S., Taurinen, J., Friedrichsen, J., Ginoudi, A., Tsaknia, T., Bellentani, G., Martinelli, F., Zampetti, S., Kalivitis, N., Kanakidou, M. (submitted). *Pedagogical model for teacher education on climate change*. In *Proceedings of the 4th World Conference on Physics Education (WCPE 2024), Krakow, Poland*. World Conference on Physics Education.

Loughran, J., Mulhall, P., & Berry, A. (2008). Exploring Pedagogical Content Knowledge in Science Teacher Education. *International Journal of Science Education*, 30(10), 1301–1320. https://doi.org/10.1080/09500690802187009

Luft, J. A., & Hewson, P. W. (2014). Research on teacher professional development programs in science. In S. K. Abell & N. Lederman (Eds.), *Handbook of research in science education* (2nd ed., pp. 889-909). Taylor and Francis.

Michailidi, E., & Stavrou, D. (2021). Mentoring in-service teachers on implementing innovative teaching modules. *Teaching and Teacher Education, 105*, 103414.

Monroe, M. C., Plate, R. R., Oxarart, A., Bowers, A., & Chaves, W. A. (2019). Identifying effective climate-change education strategies. *Environmental Education Research, 25*(6), 791–812.

Nadelson L. S. (2021) Makerspaces for rethinking teaching and learning in K–12 education: Introduction to research on makerspaces in K–12 education special issue. *The Journal of Educational Research, 114*(2), 105-107. https://doi.org/10.1080/00220671.2021.1872473OECD (2020). *Education policy outlook: Finland. OECD Education Policy Outlook series.*

OECD. https://www.oecd.org/education/policy-outlook/country-profile-Finland-2020.pdf

Oliveira, A. W. (2010). Improving teacher questioning in science inquiry discussions through professional development. Journal of Research in Science Teaching, 47(4), 422–453. https://doi.org/10.1002/tea.20345

Opfer, V. D., & Pedder, D. (2011). Conceptualizing Teacher Professional Learning. Review of Educational Research, 81(3), 376–407. https://doi.org/10.3102/0034654311413609

Pepper, D. (2011). Assessing Key Competences across the Curriculum — and Europe. *European Journal of Education, 46*, 335-353. https://doi.org/10.1111/j.1465-3435.2011.01484.

Rasa, T., Palmgren, E., & Laherto, A. (2022). Futurising science education… *Instructional Science, 50*(3), 425–447.

Rossi, C. (2023). *Pedagogical model for teacher education on climate change within the European CLIMADEMY project* (Master's thesis). University of Bologna.

Satanassi, S., Branchetti, L., Fantini, P., Casarotto, R., Caramaschi, M., Barelli, E., & Levrini, O. (2023). Exploring the boundaries in an interdisciplinary context. *Science & Education, 32*(5), 1287–1320.

Scott, G., & Yates, K. W. 2002. Using successful graduates to improve the quality of undergraduate engineering programmes. *European Journal of Engineering Education, 27*(4), 363-378.

Siponen, J., Salovaara, J. J., Santala, M., Vesterinen, V.-M., Tolppanen, S., Lauri, A., Lavonen, J., & Riuttanen, L. (2024). Climate change competence: a view of professionals advancing climate change action. Environmental Education Research. https://doi.org/10.1080/13504622.2024.2431200

Stoll, L., Bolam, R., McMahon, A., Wallace, M., & Thomas, S. (2006). Professional learning communities: A review of the literature. *Journal of Educational Change*, 7(4), 221–258.

Stratton S.K., Hagevik R., Feldman A., Bloom M. (2015) Toward a Sustainable Future: The Practice of Science Teacher Education for Sustainability. In: Stratton S., Hagevik R., Feldman A., Bloom M. (eds) *Educating Science Teachers for Sustainability*. ASTE Series in Science Education. Springer, Cham. https://doi.org/10.1007/978-3-319-16411-3_23

Tasquier, G., Levrini, O., Laherto, A., Rasa, T., Chan, J., Hyyppä, L., & Satanassi, S. (2023). *Model for science education for the society of acceleration and uncertainty* (Deliverable 4.4). Zenodo. https://doi.org/10.5281/zenodo.10048031

Taurinen, J., Vesterinen, V. M., Veijonaho, S., Siponen, J., Riuttanen, L., & Ruuskanen, T. (2024). Climate change competencies from perspective of Finnish youth. Journal of Youth Studies, 1–20. https://doi.org/10.1080/13676261.2024.2343724

Van den Bergh, L., Ros, A., & Beijaard. D. (2015). Teacher learning in the context of a continuing professional development programme: A case study. *Teaching and Teacher Education*, 47(1), 142–150. https://doi.org/10.1016/j.tate.2015.01.002

van Ginkel, G., Oolbekkink, H., Meijer, P. C., & Verloop, N. (2016). Adapting mentoring to individual differences in novice teacher learning: The mentor's viewpoint. T*eachers and Teaching: Theory and Practice*, 22(2), 198-218.

Voogt, J., & Roblin, N.P. (2012). A comparative analysis of international frameworks for 21st century competencies: Implications for national curriculum policies. *Journal of Curriculum Studies, 44*(3), 299-321. https://doi.org 10.1080/00220272.2012.668938

Weeden, P., Winter, J. & Broadfoot, P. 2002. *Assessment. What's in it for schools?* London: Routledge Falmer.

Wiliam, D. (2000). The meanings and consequences of educational assessments. *Critical Quarterly, 42*(1), 105-127.

Zhai, Y., Tripp, J., & Liu, X. (2024). Science teacher identity research: A scoping literature review. *International Journal of STEM Education, 11*(1), 20.

References on Assessment

Anderson, L. W. and Krathwohl, D. R., et al (Eds.) (2001). *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*. Allyn & Bacon.

Andrade H. L. (2019). A Critical Review of Research on Student Self-Assessment. *Frontiers in Education, 4*, https://doi.org/10.3389/feduc.2019.00087.

Atjonen, P. (2015). "Your career will be over"—Power and contradictions in the work of educational evaluators. *Studies in Educational Evaluation*, *45*, 37-45.

Brady, L. (2011). Assessing Values Education: A Tentative Exploration. *Curriculum Perspectives, 31*(3), 49–55.

Bell, B. & Cowie, B. (2001), The characteristics of formative assessment in science education. *Science Education, 85*(5), 536-553. https://doi.org/10.1002/sce.1022

Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability (formerly: Journal of Personnel Evaluation in Education)*, *21*(1), 5-31.

Bianchi, G., Pisiotis, U., Cabrera Giraldez, M. (2022). *GreenComp – The European sustainability competence framework*. Publications Office of the European Union, Luxembourg. https://doi.org/10.2760/13286, JRC128040.

Brown, T., Rongerude, J., Leonard, B., & Merrick, L. C. (2021). Best Practices for Online Team-Based Learning: Strengthening Teams through Formative Peer Evaluation. *New Directions for Teaching and Learning, 2021*, 53– 64. https://doi.org/10.1002/tl.20436

Curren, R., & Kotzee, B. (2014). Can virtue be measured? *Theory and Research in Education, 12*(3), 266–282. https://doi.org/10.1177/1477878514545205

Dawson, P. (2017) Assessment rubrics: towards clearer and more replicable design, research and practice. *Assessment & Evaluation in Higher Education, 42*(3), 347-360.

Doran, R. L., & Tamir, P. (2002). *Science educator's guide to laboratory assessment*. NSTA press.

Flowers, A., Carroll, J., Green, G., & Larson, L. (2015). Using art to assess environmental education outcomes. *Environmental Education Research, 21*(6), 846–864. https://doi.org/10.1080/13504622.2014.959473

Frederik, I., Sonneveld, W. & de Vries, M.J. (2011). Teaching and learning the nature of technical artifacts. *International Journal of Technology and Design Education, 21*, 277–290. https://doi.org/10.1007/s10798-010-9119-3

Granit-Dgani, D., Kaplan, A., & Flum, H. (2017). Theory-based assessment in environmental education: a tool for formative evaluation. *Environmental Education Research, 23*(2), 269–299. https://doi.org/10.1080/13504622.2016.1144172

Grob, R. , Holmeier, M. , & Labudde, P. (2017). Formative Assessment to Support Students' Competences in Inquiry-Based Science Education. *Interdisciplinary Journal of Problem-Based Learning, 11*(2). https://doi.org/10.7771/1541-5015.1673

Harris, C. J., Krajcik, J. S., Pellegrino, J. W., & DeBarger, A. H. (2019). Designing Knowledge-In-Use Assessments to Promote Deeper Learning. *Educational Measurement: Issues and Practice, 38*(2), 53–67. https://doi.org/10.1111/emip.12253

Hattie, J. (2009). Visible learning: A synthesis of over 800 meta-analyses relating to achievement. New York, NY: Routledge.

Jahnukainen, M. 2011. Different strategies, different outcomes? The history and trends of the inclusive and special education in Alberta (Canada) and in Finland. Scandinavian Journal of Educational Research, 55(5), 489–502.

Johnson, B., & Manoli, C. C. (2011). The 2-MEV Scale in the United States: A Measure of Children's Environmental Attitudes Based on the Theory of Ecological Attitude. *The Journal of Environmental Education, 42*(2), 84–97. https://doi.org/10.1080/00958964.2010.503716

Juuti, K., Lavonen, J. & Salmela-Aro, K. (Eds.) (2022). *Projektioppiminen luonnontieteissä [Project-Based learning in Sceince Education]*. Gaudeamus. https://doi.org/10.31885/9789523458437

Karpudewan, M., Roth, W.M. & Bin Abdullah, M. N. S. (2015) Enhancing Primary School Students' Knowledge about Global Warming and Environmental Attitude Using Climate Change Activities. *International Journal of Science Education, 37*(1), 31-54, https://doi.org/10.1080/09500693.2014.958600

Kimball, M. (2005). Database e-portfolio systems: A critical appraisal. *Computers and Composition*, *22*(4), 434-458.

Kimbell, R. 2012. The origins and underpinning principles of e-scape. International Journal of Technology and Design Education, 22(2), 123-134.

Kollmuss, A. & Agyeman, J. (2002). Mind the Gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research, 8*(3). 239-260, https://doi.org/ 10.1080/13504620220145401

Kloser, M., Borko, H., Martinez, J.F., Stecher, B., & Luskin, R. (2017), Evidence of Middle School Science Assessment Practice From Classroom-Based Portfolios. *Science Education, 101*(2), 209-231. https://doi.org/10.1002/sce.21256

Krajcik, J. S., & Czerniak, C. M. (2013). *Teaching science in elementary and middle school: A project-based approach*. Taylor and Francis.

Leighton, J. P., & Gierl, M. J. (eds.) (2007). *Cognitive diagnostic assessment for education: Theory and applications*. (New York, NY, US: Cambridge University Press).

Manoli, C., Johnson, B.,& Dunlap, R. (2007). Assessing Children's Environmental Worldviews: Modifying and Validating the New Ecological Paradigm Scale for Use With Children. *The Journal of Environmental Education, 38*, 3-13. 10.3200/JOEE.38.4.3-13. https://www.researchgate.net/publication/254345096_Assessing_Children's_Environmental_Worldviews_Modifying_and_Validating_the_New_Ecological_Paradigm_Scale_for_Use_With_Children

Marshall, J. A. , & Harron, J. R. (2018). Making Learners: A Framework for Evaluating Making in STEM Education. Interdisciplinary Journal of Problem-Based Learning, 12(2). Available at: https://doi.org/10.7771/1541-5015.1749]

McAlpine, M. (2002). *Principles of Assessment* https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=ea2226f3f264a33f260adf7a516ccc81f09c5ca9

McMillan, J.H. (ed.) (2013). *Handbook of Research on Classroom Assessment*. SAGE

Merttens, R. (1996). Assessing Children's Personal Development: The Ethical Implications. In J.M. Halstead & M.J.Taylor (Eds.), *Values in Education and Education in Values* (pp. 191-202). London: Falmer.

Mislevy, R., & Haertel, G. (2006). Implications of evidence-centered design for educational testing. *Educational Measurement: Issues and Practice*, 25(4), 6– 20. https://doi.org/10.1111/j.1745-3992.2006.00075.x

Nadelson L. S. (2021) Makerspaces for rethinking teaching and learning in K–12 education: Introduction to research on makerspaces in K–12 education special issue. *The Journal of Educational Research 114*(2), 105-107. https://doi.org/10.1080/00220671.2021.1872473

OECD (2007). *PISA 2006: Science competencies for tomorrow's world, volume 1: Analysis*. Paris: OECD.

OECD (2013). *PISA 2012. Results in focus. What 15-year-olds know and what they can do with what they know.* Paris: OECD Publishing. Retrieved from http://www.oecd.org/pisa/keyfindings/pisa-2012-results-overview.pdf

OECD (2020). Education policy outlook: Finland. OECD Education Policy Outlook series. OECD. https://www.oecd.org/education/policy-outlook/country-profile-Finland-2020.pdf

Patton, M. (2011). Developmental evaluation. New York, NY: Guilford press.

Parker, M., Ndoye, A., & Ritzhapt, A. (2012). Qualitative analysis of student perceptions of e-portfolios in a teacher education program. Journal of Digital Learning in Teacher Education, 28(3), 99-107

Pepper, D. (2011). Assessing Key Competences across the Curriculum — and Europe. *European Journal of Education, 46*, 335-353. https://doi.org/10.1111/j.1465-3435.2011.01484.x

Roczen, N., Kaiser, F. G., Bogner, F. X., & Wilson, M. (2014). A Competence Model for Environmental Education. *Environment and Behavior, 46*(8), 972-992. https://doi.org/10.1177/0013916513492416

Rosenheck, L., Lin, G.C., Nigam, R., Nori, P. and Kim, Y.J. (2021), "Not all evidence is created equal: assessment artifacts in maker education", *Information and Learning Sciences*, *122* (3/4), 171-198. https://doi.org/10.1108/ILS-08-2020-0205

Scott, G., & Yates, K. W. 2002. Using successful graduates to improve the quality of undergraduate engineering programmes*. European Journal of Engineering Education, 27*(4), 363-378.

Shepardson, D. P. Niyogi, D., Choi R. & Charusombat, U. (2009) Seventh grade students' conceptions of global warming and climate change. *Environmental Education Research, 15*(5), 549-570. https://doi.org 10.1080/13504620903114592

Siponen, J., Salovaara, J. J., Santala, M., Vesterinen, V.-M., Tolppanen, S., Lauri, A., Lavonen, J., & Riuttanen, L. (2024). Climate change competence: a view of professionals advancing climate change action. *Environmental Education Research*. https://doi.org/10.1080/13504622.2024.2431200

Vesterinen, V.M., Vilhunen, E., Lavonen, J., Riuttanen, L.& Salmela-Aro, K. (2025 in Press) *Supporting upper secondary physics teachers in project-based climate education through research-practice partnership*. K. Gunckel & G.D. Ceyhan (Eds.) Handbook of Climate Change Research in Transdisciplinary Education: Section 3: Climate Change and Teacher Education

Voogt, J., & Roblin, N.P. (2012). A comparative analysis of international frameworks for 21st century competencies: Implications for national curriculum policies. *Journal of Curriculum Studies, 44*(3), 299-321. https://doi.org 10.1080/00220272.2012.668938

Webb, M. & Jones, J. 2009. Exploring tensions in developing assessment for learning. Assessment in Education: Principles, Policy & Practice, 16(2), 165–184.

Wiliam, D. (2000). The meanings and consequences of educational assessments. *Critical Quarterly*, *42*(1), 105-127.

Weeden, P., Winter, J. & Broadfoot, P. 2002. Assessment. What's in it for schools? London: Routledge Falmer.

Zubizarreta, J. 2009. The learning portfolio: Reflective practice for improving student learning. John Wiley & Sons.

Annex A - Guidelines to point out learning outcomes

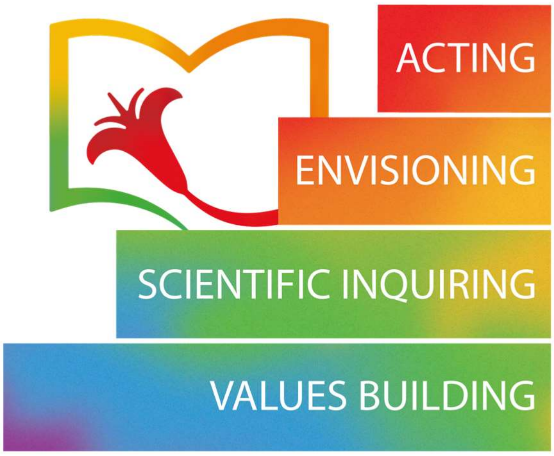
Learning Outcomes

The learning outcomes principle, emphasising and clarifying what a learner is expected to know, be able to do, and understand at the end of a learning process, now underpins most European education and training systems (Cedefop, 2016; 2021). Learning outcomes are statements that are described in the three components of a competence (Knowledge, Skill and Attitude) and are supposed to be specific to the teaching activity.
To facilitate reasoning, the following table reports verbs that can refer to the three different components of a competence (Knowledge, Skill, Attitude).

Proposed verbs for writing Learning Outcomes		
Knowledge	**Skills**	**Attitudes**
Explain	Demonstrate	Advocate
Describe	Operate	Participate
Compare	Perform	Reflect
Analyze	Create	Engage
Summarize	Assemble	Support
Identify	Execute	Promote
Evaluate	Design	Commit
Understand	Test	Accept
Outline	Construct	Appreciate
Define	Model	Value
Present	Build	Respect

In the following, lists of possible learning outcomes are reported. They have been extracted from an analysis of the activities carried out in CLIMADEMY are described in the Deliverable D2.1.

Learning Outcomes and linked Activities in the context of CLIMADEMY



Values Building

Knowledge

- Identify the intrinsic and instrumental values of ecosystems and biodiversity in the context of climate change making sense of the interconnectedness between human and more than human
- Explain ethical principles related to climate justice, intergenerational equity, and the rights of future generations.
- Describe diverse cultural and indigenous values regarding the environment and their relevance to climate action.
- Assess the social, economic, and political impacts of climate change on vulnerable communities.
- Compare the principles of sustainability and their role in fostering climate-resilient societies.
- Understand multiple worldviews and cultural differences, and promote a sense of an interdependent global cultural system.
- Recognize one's own and others' social and environmental values, their influence on behavior, and consequent impacts on the environment, contribution to climate change, and effect on human lives and ecosystems.

Skills

- Evaluate personal and societal values critically to identify behaviours contributing to climate change and ways to change them.
- Apply ethical reasoning to make decisions that balance environmental, social, and economic considerations.
- Facilitate discussions about values, attitudes, and priorities in addressing climate challenges acknowledging diverse worldviews, and promoting constructive dialogue
- Integrate values of sustainability into concrete actions at personal, community, and institutional levels.
- Developing empathetic relationships to understand diverse perspectives on climate change and its impacts.

- Utilize active problem-solving to address climate challenges and promote solutions that align with ecological and social welfare

Attitudes

- Demonstrate empathy and solidarity for communities most affected by climate change, especially vulnerable groups.
- Commit to value and protect nature, adopting and promoting sustainable practices in all areas of life.
- Respect the natural environment and its interconnected systems, recognizing the nature and biodiversity intrinsic worth and the need for preservation.
- Maintain hope and resilience, feeling entitled to contribute to global climate action.
- Embrace a sense of responsibility to address climate injustices and prioritize equitable solutions.
- Advocate for climate justice and promote sustainable practices.
- Respect cultural and environmental diversity in addressing climate change challenges.

Values Building

Activities in Schools

Values Mapping Exercise: Students create a "values map" where they categorize different environmental issues (such as deforestation, water pollution, etc.) based on their ecological, social, and economic value. This exercise can be done using a large piece of paper or digitally with tools like mind-mapping software.

Biodiversity Exploration: Students participate in a nature walk, identifying local plant and animal species. Then, they create a visual or digital presentation explaining the importance of biodiversity and the impact of climate change on local ecosystems. This emphasizes both the value of nature and the role of ecosystems in sustaining life.

Climate Justice Debate: Students participate in a debate about the ethical dimensions of climate change, with one side supporting urgent global action and the other discussing the complexities of policy implementation. This develops communication and advocacy skills while fostering critical thinking on climate justice.

Eco-Club form of involvement: Students join or form an eco-club at school where they take part in regular activities such as organizing a recycling program, conducting environmental awareness campaigns, or creating sustainable gardens. This activity nurtures a sense of responsibility and commitment to environmental causes.

Sustainability Action Plan for School: Students collaborate to create a sustainability action plan for their school, incorporating values of sustainability into everyday practices (e.g., reducing energy use, waste management, sustainable sourcing). They present their plan to school administrators for potential implementation.

Climate Change Storytelling: Students learn about the experiences of vulnerable communities impacted by climate change (e.g., small island nations, Indigenous peoples, low-income communities). They create and share personal stories or presentations to highlight the human cost of climate change, fostering empathy and awareness.

Climademy Activities

Hyytiälä science trail (Finnish Hub)
The Biodiesel Story (Italian Hub)
Data Humanism: Exploring the World through Your Story (Italian Hub)
Working on understanding and valuing emotions (Climademy Summer School)
Climate Fresk (Climademy Summer School)

Scientific Inquiring

Knowledge

- Identify the scientific principles that underpin climate systems and climate change.
- Explain the methods and tools used by scientists to study climate change, including climate modeling, data collection, experimental design, and fieldwork.
- Present the evidence used in climate science, such as temperature records, ice core data, and satellite observations.
- Describe how scientific research contributes to climate change mitigation and adaptation.
- Compare anthropogenic and natural factors influencing climate change.
- Analyze climate data sets, graphs, and models to identify patterns, trends, anomalies, and potential causes of observed phenomena.
- Recognize how climate science integrates principles from physics, chemistry, biology, and social sciences.
- Understand the role of uncertainty and variability in climate predictions and the significance of peer review in scientific validation.
- Evaluate sources: Critically assess the reliability and validity of scientific literature and data related to climate change.
- Synthesize interdisciplinary knowledge: Integrate concepts from physics, chemistry, biology, and social sciences to form a holistic understanding of climate change.

Skills

- Apply scientific methods to assess the impacts of climate change on ecosystems.
- Design studies or projects addressing climate challenges by collaborating with researchers and stakeholders.
- Develop research questions and hypotheses related to the causes, impacts, or solutions to climate change.
- Design and conduct experiments or observational studies to test hypotheses about climate change and its effects.
- Use scientific tools: Apply tools like geographic information systems (GIS), climate models, and statistical software to explore climate dynamics.
- Communicate and present scientific results and their implications through reports, presentations, and visualizations.
- Demonstrate curiosity and a willingness to explore new scientific information related to climate change.

Attitudes

- Value evidence-based decision-making and scientific research in addressing climate change.

- Promote scientific literacy within your community to increase awareness of climate issues.
- Support the integration of scientific findings into public policy and community action.
- Maintain an openness to new ideas and findings, including interdisciplinary approaches and alternative hypotheses.
- Value teamwork and collaboration across disciplines and communities in advancing climate science.
- Interest and care about the short and long-term impacts of action

Scientific Inquiring

Activities in Schools

Weather Data Collection and Analysis: Students gather local weather data (e.g., temperature, precipitation) over a set period and analyze trends. They could use tools like weather stations or online databases to study patterns and relate them to broader climate trends, thus applying scientific principles to real-world data.

Climate Science Experiments: Students conduct simple experiments to explore concepts such as the greenhouse effect, ocean acidification, or the impact of pollutants on plant growth. They document their results, analyze the data, and present their findings, helping them apply scientific inquiry methods.

Science Fair with Climate Solutions Projects: Students design and present science fair projects that address climate change solutions (e.g., alternative energy sources, water conservation technologies, sustainable farming practices). The emphasis is on using scientific evidence to develop and present feasible solutions to climate problems, fostering a value for scientific inquiry.

Citizen Science Project Participation: Students participate in a citizen science project related to climate change, such as monitoring local air quality or tracking species migration patterns in response to changing temperatures. This reinforces the importance of scientific research in addressing environmental issues and encourages students to contribute to real-world data collection.

Climate Data Analysis: Students analyze real climate data from global sources like NASA, NOAA, or Copernicus. They examine temperature trends, carbon dioxide levels, and other climate indicators. Students then summarize the data to explain the link between human activities (such as fossil fuel consumption) and climate change.

Climate Science Research Journal: Students maintain a research journal where they record new scientific information about climate change (e.g., recent studies, emerging technologies, climate data). They reflect on how the information challenges or supports existing knowledge and contributes to ongoing learning.

Climademy Activities

Effect of CO2 on Climate Change (Greek Hub)
Correlation between CO2 emissions and temperature rise (Greek Hub)
Carbon tree workshop (Finnish Hub)
Learning about climate change through project-based learning (Finnish Hub)
Photosynthesis and modelling workshop (Finnish Hub)
Laboratory activities: Benard's Cells (Italian Hub)
Theoretical and practical training in satellite data (German Hub)
Role-playing game for the Greenhouse Effect (Climademy Summer School)

Envisioning

Knowledge

- Explain the potential future impacts of climate change on ecosystems, societies, and economies.
- Discuss various climate change scenarios based on current data and models.
- Identify strategies for mitigating and adapting to climate change in different sectors.
- Understand futures thinking: Explain the principles of futures thinking and its relevance in addressing climate change challenges.
- Identify Pathways for Change: Understand various potential future scenarios and the factors that influence these pathways.
- Recognize historical patterns of climate change and how past decisions have shaped current environmental conditions.
- Understand how envisioning sustainable futures requires interconnections between systems (integrating social, economic, and environmental systems).

Skills

- Use climate models and data to develop alternative future scenarios that illustrate the impacts of climate change.
- Design practical solutions for climate adaptation and mitigation at local and global levels.
- Create shared visions for climate action by collaborating with stakeholders from diverse sectors.
- Communicate and represent envisioned futures effectively through diagrams, storytelling, simulations, etc.
- Develop action plans that align with global climate goals and address specific local needs.
- Analyze current trends (e.g., energy use, population growth) to anticipate their implications for climate change.

Attitudes

- Value long-term planning and collective action to achieve sustainable futures.
- Embrace responsibility for taking action to ensure a climate-resilient future for all.
- Support the inclusion of diverse perspectives, including those of marginalized communities, in climate solutions.
- Foster a mindset of hope and determination, recognizing the power of individuals and communities to influence change.
- Appreciate the importance of including different cultural, social, economic, and multidisciplinary perspectives in envisioning processes.
- Open-Mindedness: Develop courage and willingness to explore innovative and unconventional ideas for addressing climate change.
- Reflect on continuously evaluating and adapting visions for sustainability in response to new insights.

Envisioning

Activities in Schools

Future Climate Scenario Workshop: Students participate in a workshop where they are given data about current climate trends and work in groups to create detailed 'future scenarios' of climate impacts in 2050, 2100, and beyond. They can present their findings to the class, emphasizing predictions about ecosystems, agriculture, and urban areas.
Design a Sustainable City: Students work in teams to design a 'climate-resilient' city using sustainable practices (e.g., renewable energy sources, green buildings, efficient transportation). They create models, presentations, or even virtual simulations.
Interactive Climate Maps: Students use online tools (like interactive climate change maps) to visualize and predict future climate impacts (e.g., rising sea levels, and temperature changes). Students can explore different regions and see how ecosystems, populations, and economies will be affected.
Climate Action Pledge: Students create personal climate action pledges and share them with the school community. This could include a commitment to reducing waste, using less plastic, conserving water, or educating others on sustainability. The pledges are displayed prominently in school hallways or online, reinforcing the importance of collective action.
Climate Model Exploration: Students work with simplified climate models to explore different scenarios (e.g., 1.5°C vs. 2°C global warming). They analyze potential outcomes for temperature rise, sea-level rise, and other climate factors, discussing the consequences of each scenario for global and local environments.
Climate Mitigation and Adaptation Plans: Students design strategies for climate mitigation and adaptation within a specific sector (e.g., agriculture, energy, transportation). They present their plans with a focus on how these strategies could reduce emissions or help communities adapt to climate change.

Climademy Activities

IPCC Interactive Atlas workshop (Finnish Hub)
Modelling simulation – Theory and hands-on experience (German Hub)
Teaching CC through Atlas platform data (Italian Hub)
Climate and Data (Greek Hub)
Designing and Prototyping a Sustainable Public Transport Vehicle (Climademy Winter School)

Acting

Knowledge

- Describe key global, national, and local policies and identify relevant stakeholders to address climate change issues.
- Understand and explain how local, community-based, and individual actions contribute to broader climate solutions.
- Identify barriers to effective climate action and potential solutions.
- Evaluate the impact of individual actions on reducing carbon footprints.
- Assess the intersection of climate change and other global issues such as poverty, health, and inequality.

Skills

- Implement sustainable practices in daily life, such as waste reduction, energy conservation, sustainable transport use, reduce of personal and organizational carbon footprints.
- Organize and lead community-based climate action initiatives.
- Develop and carry out climate solutions in the workplace or community by collaborating with stakeholders.
- Demonstrate resilience in the face of climate challenges, staying motivated and focused on solutions.
- Monitor and evaluate the effectiveness of climate actions, adjusting strategies as needed to meet targets.

Attitudes

- Take responsibility for being an active participant in climate action efforts.
- Promote collaboration across sectors and communities to address climate change effectively.
- Foster a sense of accountability for personal and community contributions to climate change and their solutions.
- Cultivate a mindset open to innovative solutions and creative approaches to tackle climate-related challenges.
- Embrace the value of inclusive and collaborative efforts across diverse communities and stakeholders in addressing climate change.
- Advocate for climate policies and actions at local, national, and global levels.
- Communicate climate science within the community, accessibly, while still embracing the complexity of the phenomena

Acting

Activities in Schools

Climate Change Policy Analysis: Students research climate policies at different levels (local, national, global) and write reports or create presentations comparing them. They can use online resources, government documents, and case studies to analyze the effectiveness of these policies in reducing carbon emissions or promoting renewable energy.

Carbon Footprint Calculation: Students calculate their own carbon footprints using online calculators, and then identify practical strategies to reduce them. For example, they might adjust their daily habits (e.g., biking instead of driving, reducing energy use) and track their progress over time.

Community Clean-Up Event: Students organize and participate in a community clean-up event, such as cleaning a local park, beach, or forest area. Through this activity, students actively contribute to reducing pollution and demonstrate a personal commitment to climate action.

Reduce, Reuse, Recycle Challenge: Students organize a "Reduce, Reuse, Recycle" challenge within their school or local community. Participants track their waste reduction, recycling efforts, and consumption habits over a set period. Students can then create a report or presentation to showcase how small lifestyle changes can significantly impact the environment.

Role-Play Climate Action: In a classroom role-play activity, students take on the roles of different stakeholders (e.g., a government official, business leader, environmental activist, or community member) and work together to design a climate action strategy. This helps students understand the varied responsibilities and contributions of each group.

Advocacy Letter Writing Campaign: Students write letters or create petitions advocating for stronger climate policies, either locally (e.g., supporting renewable energy projects in the community) or globally (e.g., urging action on climate agreements). They then send these letters to relevant policymakers.

Climademy Activities

Climate Fresk Activity (Climademy Summer School)
Climate Call (Climademy Winter School)

Resources

Anderson, L., & Krathwohl, D. A. (2001). *Taxonomy for learning, teaching and assessing: A revision of Bloom's Taxonomy of Educational Objectives*. New York: Longman.

Bianchi, G., Pisiotis, U., Cabrera Giraldez, M. GreenComp – *The European sustainability competence framework*. Bacigalupo, M., Punie, Y. (editors), EUR 30955 EN, Publications Office of the European Union, Luxembourg, 2022; ISBN 978-92-76-46485-3, doi:10.2760/13286, JRC128040.

Bloom, B. S.; Engelhart, M. D.; Furst, E. J.; Hill, W. H.; Krathwohl, D. R. (1956). *Taxonomy of educational objectives: The classification of educational goals*. Handbook I: Cognitive domain. New York: David McKay Company.

Cedefop (2022). *Defining, writing and applying learning outcomes: a European handbook - second edition.* Luxembourg: Publications Office of the European Union. http://data.europa.eu/doi/10.2801/703079

Kennedy, D. (2006) *Writing and using learning outcomes: a practical guide*, Cork: University College Cork.

Taurinen, J., Vesterinen, V. M., Veijonaho, S., Siponen, J., Riittanen, L., & Ruuskanen, T. (2024). Climate change competencies from perspective of Finnish youth. *Journal of Youth Studies*, 1–20. https://doi.org/10.1080/13676261.2024.2343724

Learning Outcomes: Centre for the Integration of Research, Teaching and Learning (CIRTL), University College Cork.

An introduction to writing effective learning outcomes. Centre for Teaching and Learning, University of Oxford

Annex B - Assessment tools: further guidelines and examples

Diagnostic Assessment: Assessment before learning
The aim of diagnostic, declarative or planning assessment is to find the values, skills and perceptions and knowledge needed by the students in climate education. Tools for diagnostic assessment include various tests, teacher questioning and observations (Leighton & Gierl, 2007). The questions posed by the teacher directs the student to look at certain characteristics of climate education. The student's response tells the teacher what the student thinks about the topic. For example, a review related to the mitigation of climate change can begin with the question: "How can you save energy?" and "How can you save materials?"
A diagnostic test, Kahoot (https://kahoot.com/) or Socrative (https://www.socrative.com/) activity could also be used to map the students' conceptions or skills: Which of the following activities consume energy most in European Union a) education, b) transport, c) food and beverages. The teacher asks questions they know as being critical to the success of the work: "How are the results reported?", "What keywords did you think you should use in a search?" In a similar way, it is possible to map the way in which the students have understood the aims of the learning activity: "What and how we are evaluating in this activity?" The questions help students to think about the aims of the learning process.

Karpudewan et al. (2015) used following questions for mapping students' pre-conceptions in their study on child-centered, 5E[2] learning cycle-based climate change activities:
- What is global warming?
- What do you understand about global warming?
- What is the cause for global warming?
- If we had a way of making sure that there was no rubbish in rivers, is that going to help reduce global warming?
- Explain how we combat global warming by making sure the rivers are clean?
- Do you turn off the air conditioning or other electrical appliances when not in use? How often do you perform this behaviour?

In the context of diagnostic assessment, students often respond in an unexpected way because the topic has not yet been learned and they do not know the concepts or skills needed in the learning activity. Therefore, it is particularly important to provide encouraging feedback to students. After the student's answer, a teacher naturally continues with a follow-up question. If the answer is vague, the student may be given an opportunity to modify the answer. The teacher can repeat or slightly modify the student's answer, for example, by asking, "Do you mean that..." (repeating the answer in your own words), "You bring up perspectives A and B, would there be other perspectives?", "What do you think about C?" The types of feedback given by a teacher can be grouped as follows:
- Encouraging feedback: emphasizing competence;

[2] The "5E" refers to the five phases of the Learning Cycle, namely Engage, Explore, Explain, Elaborate, and Evaluate.

- Evaluative feedback: highlight positive perspectives and ask to look at it from another perspective;
- Guiding feedback: how the objectives should be considered in the future.

Formative Assessment: Assessment during learning

Formative assessment is used for supporting the students' learning process. Moreover, peers could be active in giving feedback during the process, such as during the communication sessions, which are typically used within inquiry or project type of learning. For example, students could be asked to communicate the phase of their learning to other students and the teacher after the students have formulated the question, problem or challenge according to which they will learn. Typical type of formative assessment are:

- Observations during in-class activities; of students non-verbal feedback during lecture
- Homework exercises as review for exams and class discussions
- Reflections in portfolio or in other type of document that are reviewed periodically during the semester
- Question and answer sessions, both formal—planned and informal—spontaneous
- Conferences or discussions between the instructor and student (and parent) at various points in the semester
- In-class activities where students informally present their results
- Student feedback collected by periodically answering specific question about the instruction and their self-evaluation of performance and progress (Bell & Cowie, 2001)

The feedback provided by the teacher, as well as the self-assessments and peer assessments help the students to understand their learning and to identify the development of their values, attitudes, knowledge or skills and areas where competencies are not yet sufficient. The students learn to correct their mistakes and develop their working so that the goals set for their learning can be achieved. The feedback could be given orally, adding comments to the portfolio or learning diary or with structured forms. Therefore, it is important that at different stages of their learning, students communicate to the teacher and to each other about the stage of the learning process and outcomes.

Formative assessment guides regulate the student's working and learning toward the aims set for learning. Its primary function is to help students to discover what they know and how, or are able to do, and what still needs to be learned and in what way (Webb & Jones 2009). Formative assessment helps the teacher to focus his or her support and supervision on issues that students do not yet know. Formative assessment can also support the student's feeling of competence. The need for competence is one of the key basic psychological needs or motivating factors in learning.

Summative Assessment: Assessment after learning

An essential characteristic of summative assessment is making the achievement of the aims, objectives or learning outcomes and, moreover, the learning process visible. In a summative assessment attitudes, values, knowledge and skills, which have been developed or learned could be assessed. Summative assessment is based on verified evidence of how well and to what extent the student has achieved the aims set for the lesson or climate education module (Doran & Tamir, 2002). Various assessment tools, such as examinations or tests, an examination where materials or internet could be used, a screening test, and systematic use of e-portfolio could be used in summative assessment. Moreover, it is possible to assess concrete outcomes of the learning process, artefacts, such as essays, concept maps, project reports and presentations or a learning diary.

There are several points of views that should be considered while planning an examination or a test for measuring the learning outcomes. First, summative assessment as any other assessment is done according to the aims, objectives or learning outcomes descriptions of the climate education module. For the purposes of summative assessment, it is common to prepare a framework, which is used in the development of the assessment and the content to be assessed. The framework helps the design of assessment tools, such as test and test items. For example PISA Scientific Literacy Framework, introduced in the Programme for International Student Assessment (PISA) (Organisation for Economic Co-operation and Development in 2007, but revised in 2013. (OECD], 2013), have been used for the design of PISA Science test and test items. This framework initially defines three competencies, which describe the use of science subject knowledge and knowledge about science and, moreover, willingness (attitude) to use this knowledge in three situations (skills): in identifying scientific issues, in explaining scientific phenomena and in drawing evidence-based conclusions. This framework also concentrates on various situations or contexts where attitude, knowledge and skills are developed. The initial PISA framework further introduced personal, local and global situations and contexts in three main areas: science in life and health, science in the Earth and its environment, and science in technology.

Harris et al. (2019) have suggested a design process for constructing knowledge-in-use assessment tools and items. This approach provides meaningful and actionable information about students' progress toward knowledge-in-use learning goals. The design process has origins in the evidence-centered design (ECD) (Mislevy & Haertel, 2006), which has gained attention as a comprehensive approach for principled assessment design and validation. ECD provides a framework for analysing content for assessment design that can be used to specify the essential and assessable components of knowledge-in-use learning goals. We slightly modified the original test and item design model for climate knowledge-in-use (Fig.13). This model involves two phases: domain analysis, which involves unpacking of the climate competences in the performance expectations to understand the assessable components; and domain modeling, which involves item and test design including the design of item type, cognitive process and knowledge type and, moreover, the use of additional material, such as, additional text or data material. Fig.14 presents an integrated climate competence dimension map, which is recommended to construct after first unpacking disciplinary core knowledge or practices, scientific and engineering practices and values and attitudes in the context of climate competences. This climate competence dimension map has the same components as it is described in the PISA framework.

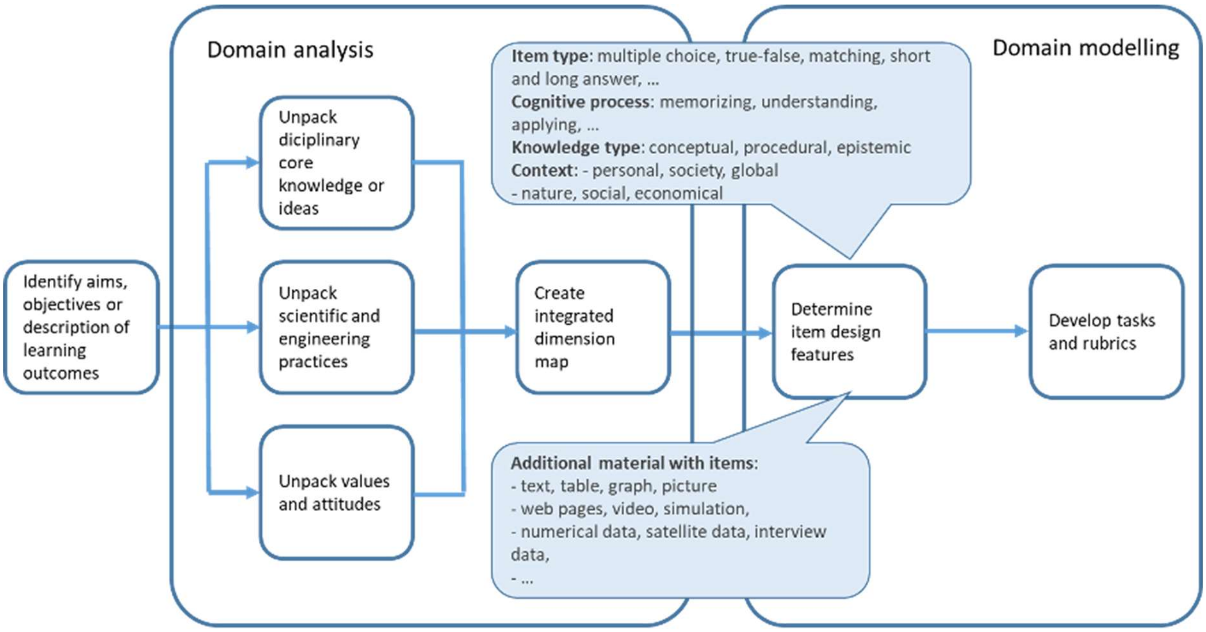


Fig.13. Design process for constructing knowledge-in-use assessment items.

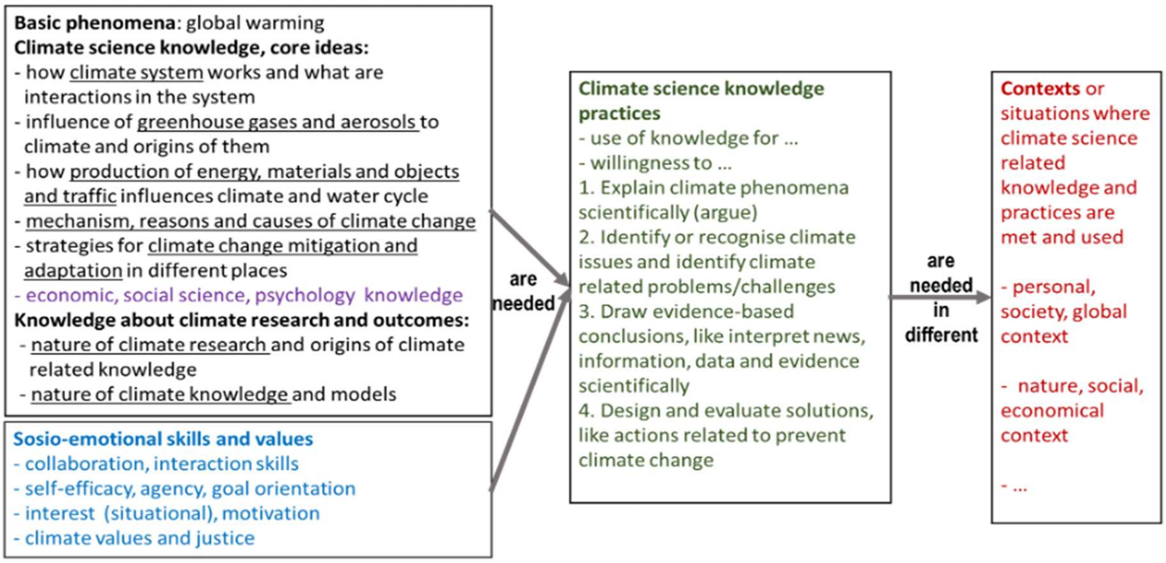


Fig. 14. Integrated climate competence dimension map

Examinations and tests are structured in several ways and several item types are used in the test, such as, objective items (true-false, multiple choice, matching, put in order, ...), short answer questions (question, fill-in, crossword, ...), essay, and problem-solving question. True or false type items are simple statements, which must be either completely true or completely false. The statement should not be very long and it is not appropriate to use statements with words like always, never, no, sometimes and often. Moreover, negative statements could be avoided.

Short answer questions could be asked using different forms, such as question, fill-in and crossword. Different type of short answer questions:

1. Definition question: require to define a concept (What is an acid?)

2. Explanation question: require to explain why something is true or how something functions (What happens in neutralisation?)
3. Example question: require a specific real-world example of a concept or phenomenon (Give example of acids)
4. Relationship questions: require to state or show how two or more things relate to one another (Are they the same? Are they different? Are they opposites?)
5. Calculation question: require to calculate or compute a numerical answer or response.
6. Graphing question: require an answer in the form of a graph (Draw a graph, which describes neutralization).

Essay test items demand long answers and it enquires the students to use knowledge rather than memorize information. Much time is required to answer this type of question as the student has to plan, organize and reflect. Student has to express his/her ideas in writing clearly and concisely hence only a few questions can be asked within the limited time in as much as the test cannot cover the whole curriculum. Example of an essay test item: Why is the average temperature of the Earth increasing?

New knowledge is learned at different levels. Firstly, it is possible to repeat what has been learned, ie. to recall the knowledge, and secondly, new knowledge could be used in a familiar context. The third level is the application of learned knowledge to new situations involving problem-solving (Fisher 1990: 1 - 28). Consequently, cognitive processes are wary between the levels and are less demanding in lower levels. Anderson and Krathwohl (2001) developed a taxonomy, which is a revision of Bloom's taxonomy, which categorizes cognitive processes in 6 levels as described in Table 2. Table also introduces test items, which aims to measure use of knowledge in a certain level of cognitive process.

Table 2. Examples of test items measuring student understanding of recycling in different levels

Cognitive process	**Verbs**	**A test item about recycling**
Remember (recognise or recall knowledge, facts or concepts)	define, describe, identify, label, list, name	What is recycling?
Understand (construction meaning from instructional message)	illustrate, compare, explain, classify, interpret, summarize	Why is recycling important?
Apply (use ideas and concepts in a new situation or in problem solving)	implement, organize, construct, demonstrate, modify, prepare, relate, solve	Give examples of recycling at home and at supermarkets. How can you develop recycling habits in your home?
Analyse (breaking something down into components, significance of components),	analyse, break down, compare, select, contrast	What happens if we stop recycling?

		What happens to materials and energy in recycling?
Evaluate (making of judgement or assessment on the basis of criteria or standards)	rank, assess, monitor, judge	Evaluate possibilities and constrains for recycling in your home city?
Create (recognise diverse elements to form a new pattern or structure)	generate, plan, develop, create, invent, construct, produce, design	Design a recycling plan for your school.

Anderson and Krathwohl taxonomy also has a knowledge dimension and introduces four types of knowledge: (1) factual knowledge; (2) conceptual knowledge; (3) procedural knowledge and (4) meta-cognitive knowledge. Epistemic knowledge is added to the original dimension.

Table 3. Knowledge dimension in Anderson and Krathwohl taxonomy.

Knowledge type	**Definition**	**Example question**
Factual knowledge	information on terminology and details	Name two greenhouse gases.
Conceptual knowledge	knowledge of different classes and categories, generalizations, theories, models and structures.	What is the reason for global warming
Procedural knowledge	knowing how to do something, algorithms, techniques, methods, and criteria for the use of knowledge.	A class decided to start measuring outdoor temperature in order to know how it is changing during one year. Present a plan for the study.
Epistemic knowledge	which knowledge is correct by one reasoning, but may be false based on another, knowledge of how new knowledge is created, justified, and used.	How do we know that the average temperature of Earth is slowly increasing?
Metacognitive knowledge	knowledge of strategies, knowledge of the cognitive requirements of the task, and knowledge of one's own strengths and weaknesses.	Evaluate your actions from the point of view of global warming

The cognitive test Shepardson (2009) used for measuring seventh grade students' conceptions of global warming and climate change is a good example of a test, which measures use of conceptual and procedural knowledge in various situations. Moreover, the items measure at least an understanding level of cognitive process.

Summative assessment can also be done by an observation form, a learning diary, a portfolio, or based on a screening test. Documents, reports, blogs, or videos produced by the students could also be assessed. Summative assessment could be implemented through the assessment of the artefact created during the learning process. A specific assessment sheet, constructed based on the aims of the learning, could be used in the assessment of the artefact.

For assessing students' answers to examination or test items, a rubric is needed. A rubric is a type of scoring guide that articulates specific components and expectations for an assignment. Rubrics can be used also for a variety of assignments, such as documents, reports, blogs, videos, portfolios, and presentations.

	Culture: Our school develops a culture of sustainability with the wider community			
	Starting	**Challenging**	**Committing**	**Transforming**
Rubric **Vision and values**	The need to examine our school's sustainability vision and values is identified	Our school undertakes an inclusive community process to develop its sustainability vision and values	There is evidence of commitment to the vision and values through all areas of school life	Core vision and values are practised, renewed and shared across communities to build more sustainable lifestyles
Core indicator	School community (students, staff and parents) has: • engaged in reviewing our current vision and values e.g. caring and respect to include EfS.	School community (students, staff and parents) has: • developed our vision and values with current and potential partners to include EfS.	Students, staff, parents and community members have: • demonstrated and communicated our sustainability vision and values in everyday practices i.e. 'walking the talk'.	Communities are: • renewing and sharing visions, values and sustainable lifestyles.
Rubric **Interconnectedness**	Our school considers how to integrate the social, environmental and economic factors of sustainability	Some of our practices reflect a balance between social, environmental and economic factors	Our school places equal value on social, economic and environmental factors when making decisions	Through a culture of sustainability, social, environmental and economic factors are integrated
Core indicator	School community (students, staff and parents) has: • considered the scope of sustainability and how it fits with educational purpose.	School community (students, staff and parents) has: • implemented strategies to integrate sustainability factors into our decision and policy making processes (e.g. item on meeting agendas.	Students, staff, parents and community members have: • reviewed our policy documents e.g. purchasing to ensure that decisions are made considering all sustainability factors.	Communities are: • making sustainability a priority in all decision making.
Rubric **Whole-school approach**	Individuals consider and identify their role in education for sustainability	Groups consider ways to coordinate and integrate their work with the school's sustainability vision	There is whole-school commitment to achieving the sustainability vision	Our school is part of a sustainable community
Core indicator	School community (students, staff and parents) has: • invited a range of people to examine how they can contribute to EfS.	School community (students, staff and parents) has: • started discussing and documenting how the EfS vision guides our sustainability actions.	Students, staff, parents and community members have: • demonstrated that our actions within and beyond the school consistently reflect our vision and values of sustainability.	Communities are: • working together to generate innovative practices and achieve sustainability goals.

Note: EfS = Education for Sustainability

Fig. 16. An example of a rubric for Education for Sustainability, published by the Government of Australia (https://cdn.environment.sa.gov.au/landscape/docs/hf/nr_amlr_aussi-sa_education_for_sustainability_rubrics_and_core_indicators.pdf)

Student self-assessment

Through self-assessment, the students find out what they have learned, compare their learning to the set aims, and strive to find out what should still be learned. They can also recall how they have engaged in the learning process and how they could engage more effectively next time. Self-assessment is thus like formative assessment and intended to support the learning process and learning outcome. It helps students to become responsible for their learning. Self-assessment also supports the development of metacognitive skills, self-confidence, and self-image. In addition to learning, the use of a self-assessment method develops readiness for further studies and adult life (Andrade, 2019).

It is known that self-assessment is challenging for students. Therefore, students' self-assessment should be supported by teacher led discussion, teacher questioning, or assigning a task. The discussion can be started by asking the student to share their experiences of their learning process in general. Next, the student could be asked to look at their own activity during the learning and to think about what kind of problems they had. Finally, the students could be encouraged to analyse how they can develop their learning. The self-assessment could be started with a question, "What was the most interesting / surprising / charming thing today?". Other examples of questions that guide the self-assessment process include: "List the three most important things you learnt today" and "What else would you have liked to learn?" Students can be asked to write the answers on a common page on a digital platform. After writing, they can be instructed to compare their responses and discuss each other's experiences. It is important to guide students to evaluate their learning in a small group, for example: "How have you succeeded in your group in collaboration, idea generation and communication?" "How can you improve your learning in a group?"

The form in Fig. 17 could be used for guiding the self-assessment. There may be fixed and open-ended questions on the form (see Table 3).

What can I do? (1 = I need exercise, 2 = moderately, 3 = well)

1. I am able to search for information.	1 2 3
2. I am able to generate ideas.	1 2 3
3. I am able to evaluate ideas.	1 2 3
4. I am able to write notes.	1 2 3
5. I am able to work in a group.	1 2 3
6. I am able to communicate.	1 2 3
7. I am able to assess my learning.	1 2 3
8. I am able to assess artefacts created during the learning process.	1 2 3

What was most interesting related to learning today?
What else would you like to learn today?

Fig.17. Example of self-assessment form of students' activities.

Peer-assessment
The group can also self-evaluate their own activities using other forms or relying on a discussion. As the group evaluates their own activities, group members become aware of how each group member and the group as a whole has worked. In peer review, a student evaluates the work of another student or a group. In this case, it is important to encourage students to be positive in the assessment and to bring up a number of perspectives. Any criticism presented should be done so constructively (Brown et al., 2021).

The Digital Portfolio - a method for Knowledge Building, Interaction, and Assessment

The digital portfolio, a briefcase or a folder refers to the collection of the displays of student assignments, descriptions of the learning process and outcomes. The display discloses the student's diverse abilities and the reached competence levels depending on the portfolio assignment type: the open assignment type reveals more detailed and unexpected information than the ready-to fill-in type (Parker et al., 2012; Kimball, 2005). The content of the portfolio, collected documents, consist of the process descriptions, the choices available, and the self-assessments/the group assessments and describe success and recognized challenges and objectives for further learning.

Alongside the authentic documentation, the portfolio consists of two more basic elements: reflection and collaboration (Zubizarreta, 2009). The portfolio develops in the portfolio process from a container to a reflective report and even to a dialog (Kimbell, 2012). The content of the portfolio diversified as the inexperienced student became accustomed to the method and the simplest documenting is transformed into a more diverse holistic or even abstract narration (See also Saarinen et al., 2021). The collected materials can be processed, reflected, immediately and/or later at an appropriate time.

Portfolio can contain a range of types of assessment: it can be shared online with the teacher when the process feedback is direct and formative by nature. If the portfolio is shared with the peers, the peer-feedback can be directed towards content or criteria and due to its formative nature, it also supports the process. Finally, the contents of the portfolio comprise the material for summative assessment purposes.

One principle of the portfolio assessment is that the working and the progress of it, the best achievements, and failures and coping with them are stored. One's own development is examined and with the help of the documentation, reflected either to construct a statement or the deepest level of reflective thinking (Kimball, 2005). Then also the mistakes and failures are seen but not emphasized in the same way as for example in the traditional assessment, which is based on the use of summative tests. On the other hand, the examination of mistakes and their corrections show versatile skills and abilities, and therefore it is desirable for the portfolio documentation to contain errors and mistakes. The portfolio assessment is an attempt to strengthen learning to learn and the self-direction as well to develop self-esteem.

When compiling the portfolio student:

- analyse, selects and sets own objectives for himself
- designs and selects studying tasks suitable to the objectives and approaches
- shows and uses information independently and adapts it
- examines and estimates own learning process and the learning results, in other words own work and working
- discerns personal strengths, subject interests and learning challenges
- considers the grounds for the successful learning and the significance of collaboration and role of own working.

It is recommended to start by a review of the portfolio, going through the principles of how the portfolio works, sectors (elements) and their role in the assessment (the criteria for assessment). The typical stages of the portfolio work carried out at schools are as follows:

1. Common and own aims or objectives for learning subject matter, knowledge and skill are set together and their assessment criteria are agreed on.
2. The learning process is designed together based on the objectives and it is carried out.
3. During and at the end of the study module the students will estimate progress independently in group and/or with teacher and they reflect the samples contained in the portfolio.
4. The student can, if so desired, distribute the samples chosen by him/her and his/her own estimate of their level and of own development to other students, teachers and possibly also

older and friends so that they can become acquainted with the working of the study module and with the encouraging assessment debate.
5. In the assessment both the results and the process descriptions, progress and enterprise are taken into consideration.

Assessing artefacts
An “artefact” refers to tangible objects or outcomes of the learning process, created by the students. These can include textual artifacts such essays, concept maps, project reports, presentations, and learning diaries, but also concrete objects such as artwork, technological objects, crafts etc., or audiovisual artefacts such as videos (Kloser et al., 2017; Rosenheck et al., 2021). Role of artefacts in learning are especially emphasized in inquiry or project-based learning. In this type of learning, students create a set of tangible artefacts, like graphs and tables with digital tools that address the driving question. These are shared artefacts, that is, publicly accessible external representations (Krajcik & Czerniak, 2013).

The produced artefacts can be used for summative assessment of the students’ learning outcomes (Rosenheck et al., 2021). Artefacts could be used also in formative, self- and peer-assessment. However, Grob et al. (2017) raise various challenges in formative assessment. Firstly, it takes time, especially, the preparation of written assessment, if they are done several times. Secondly, self- and peer-assessment also need a certain amount of practice to be effective: The students need some exercise in assessing and providing feedback before peer-assessment can really improve learning and the artefacts.

In the context of climate education, the number of points of views in the assessment of artefacts could be high. First, the starting point in assessment is in the climate competence model: Values and attitudes, scientific knowledge and ability to search new information on climate, creativity and ability to design new solutions, and action competence. Second, the artefact as such could be assessed from the ethics and aesthetic point of views and how well it communicates the “message”.

The assessment of student-produced artefacts, like all assessments, must always be based on the given assignment and the learning goals that have been set for that assignment. The two example rubrics provided below illustrate this. The first rubric is intended for evaluating a learning project in physics, where the students must produce a model that describes the movement of objects based on experimental evidence. The second rubric is meant for assessing student products created in “maker education”, and the assessment criteria reflect the learning goals of maker education. In holistic climate change education, the assessment criteria should reflect the key climate change competencies. Artefacts can also be assessed from aesthetic and ethical perspectives, whenever relevant to the learning goals: in climate change competencies, this could mean assessing the artefacts from the perspective of the competence area “Embodying sustainability values”.

Table 4. A rubric used for assessing an artefact (a model) in project-based learning (Juuti et al., 2022).

	5 Excellent	4	3 Good	2	1 Poor

Does the model answer the guiding question?					
Concepts and their use					
The produced model					
Argumentation					
Clarity and appearance					

Assessing values and attitudes
There is little research on values and attitudes in the context of climate education and what is published is typically written based on environmental attitudes and values in general.

The assessment of students' values and attitudes is concerned with formative and diagnostic assessment. The summative assessment of student values has been found to be counterproductive or even harmful and ethically questionable (Curren & Kotzee, 2014; Merttens, 1996) and high-stakes testing in ethics education has been found to be similarly counterproductive for achieving holistic ethics education (Sporre, 2019). Furthermore, depending on the local curriculum, it may be explicitly forbidden to use students' values and attitudes as basis of summative assessment or grading. Thus, assessment of values refers here to the assessment of students' environmental values for the purpose of supporting their learning process and, moreover, their future actions related to climate and environmental issues.

Values and attitudes form the foundation of climate change competences. Thus, to create optimal learning moments, it is crucial that teachers are aware of their students' values and attitudes. It is also important for students to self-assess their values to become aware of them. Several value assessment instruments have been developed that could be used, possibly in an adapted form, for student self-assessment. These include the New Environmental Paradigm Scale (NEP) and the New Environmental Paradigm Scale for Children (Anderson, 2012; Manoli, Johnson & Dunlap, 2007). The 2-MEV scale (Johnson & Manoli, 2011), intended to be used with 10 to 12-year-olds, measures the preservation and utilization dimensions of ecological values: preservation values have been found to correlate with pro-environmental behavior (Pauw & Petegem, 2013). A third scale measures the egotistic, biospheric and altruistic value orientations: the biospheric value orientation correlates with pro-environmental behavior (de Groot & Steig, 2008). Ranking tasks, in which students rank values or value statements in order of personal importance, can also be used in student self-assessment. For example, Brady (2011) suggests that students can rank following value-statements for self-assess their values (2-MEV scale):

- *I try to tell others that nature is important.*
- *To save energy in the winter, I make sure the heat in my room is not too high.*
- *I like the quiet of nature.*
- *Weeds should be killed because they take up space from plants we need.*
- *People are supposed to rule over the rest of nature.*

Teacher observations on students' behaviour, actions and talk offer information about the students' values and attitudes: Values as such are difficult to observe. This can occur during class activities in which students engage with environmental values, such as debates, dialogues, small group discussions and role-playing (Shephard, 2008). In this way, the learning and assessment of values occur simultaneously, and the teacher can use the results of this formative assessment to further support the learning of environmental values.

Flowers, Carroll, Green and Larson (2015) explored methods of using drawing assessments to assess the environmental attitudes and awareness of primary school aged children. However, they note that art methods may give different results from more traditional measurement scales depending on the learner, and thus different assessment methods should be combined to get a fuller picture of the students' values and attitudes.

Environmental values and attitudes do not exist separately from environmental knowledge. Kollmuss and Agyemann (2002) see environmental values, attitudes, knowledge and emotional involvement as forming a complex they call "pro-environmental consciousness", and Roczen et al. (2014) found that attitudes and knowledge affect each other. Thus, students' values and attitudes cannot be assessed as if they formed an area separated from their knowledge; rather, the students' knowledge should be considered when assessing their values and attitudes.

Annex C – Examples of activities for teacher education

We report here two activities that were co-designed and implemented in CLIMADEMY.
The activities are presented according to the template that we used in WP2: they appear aas teaching materials to be used in classes of secondary school students. However, the following descriptions include: a) detailed comments on how the learning objectives are pursued through the activities, b) assessment tools and c) tips on how to use these materials in contexts of teacher education (as implementation of the pedagogical model).

Examples 1 - The key concepts of complexity

General Information	
Title of activity:	**The key concepts of complexity**
Estimated duration:	23 hours: Interactive Lectures 2 hours: NetLogo simulations 1,5 hours: execution of the experiment "Bernard's cells" and analysis of the experiment by modelling it as a complex system 1,5 hours: execution of the experiment "Oscillating Reaction" analysis of the experiment by modeling it as a complex system
Target group:	Secondary students - Grade 11
Related disciplines:	**Physics** **Chemistry** **Biology** Other: links to **social sciences**, **philosophy and mathematics**

Contextual Information	
Reference to the hub:	Italian HUB
Author(s) of the activity:	Paola Fantini, Veronica Ilari
Schools/contexts where the activity was developed:	Scientific high school "Liceo Statale A. Einstein", Rimini
Schools/contexts where the activity was implemented:	Scientific high school "Liceo Statale A. Einstein", Rimini

Topic of Activity	
Fundamental scientific ideas of Climate Change	The activity introduces the key concepts of complexity without delving into mathematical formalism, but rather by qualitatively analyzing phenomena from various fields — physical (e.g., Bénard's cells), chemical (e.g., Oscillating Reactions), biological (e.g., flocking behaviour in birds, ant colonies, cloud formation), and social (e.g., segregation) — with the aim of bringing to light the fundamental principles that characterize complex systems. The main concepts addressed are: - irreducibility; - multiplicity; - circular relationship between the whole and the parts; - emergent property: unpredictable, at the level of the constituent elements, collective behaviour, meaning <u>self-organization</u> <u>emerging</u> from microscopic dynamics; - need to change the space-time scale in the description of the phenomenon; - instability as an opportunity for new 'robust' structures to emerge; - unpredictability. Although the activity does not directly address Climate Change issues, it focuses on fundamental concepts of complex systems, providing the necessary background to approach Climate Change more consciously, recognizing it as an inherently complex phenomenon involving many interconnected and irreducible elements and dimensions.

Values Building Objectives	
*Please select the **knowledge** objectives covered in the activity*	- Recognize multiple worldviews and cultural differences - Recognize the influence of social, economic, and environmental issues to values - Recognize the human and more-than-human interconnectedness - Know ethical principles, justice, and sustainable values - Know principles of nature conservation/protection • <u>Recognize the meaning and the value of the perspective of complexity to think and act for sustainability</u> • Other:

*Please select the **skills** objectives covered in the activity*	- Make ethical decisions and take action - Recognize one's own and others' values, and their consequent impacts on systems - Develop empathy - Assess personal values in relation to climate values • <u>Be willing to recognize and analyze the connectedness of social, economic, and environmental systems to identify holistic solutions</u> - Facilitate discussions acknowledging diverse worldviews - Promote constructive dialogue • <u>Other: be able to appropriate the meaning and the value of the perspective of complexity and to turn it into a "way of thinking and acting for sustainability"</u>
*Please select the **attitudinal** objectives covered in the activity*	- Commit to valuing and protecting nature - Respect and embrace cultural and environmental diversity - Show deep concern for the social and environmental impacts of climate change - Prioritize equitable and sustainable solutions • <u>Be aware of and care for one's own and others' relationship with nature and its protection</u> • Other: <u>Accept the values of the perspective of complexity as needed to think and act for sustainability</u>
Comments on how the activity can contribute to pursue the learning objectives	The <u>Value Building Knowledge</u> objective is pursued in the activity by guiding the students to ***know the basic epistemic values of the perspective of complexity*** *(in contrast to the mechanistic linear perspective): the values of systemic non-linear connections, the value of contingency and probabilistic thinking, the value of multi-dimensionality and of the circular relationship between the dimensions, the values of recognising links between what appears fragmented or separate (holistic view).* This knowledge of the epistemic values of complexity forms the basis for developing <u>Values Building Skills</u>, skills that are nurtured by recognizing the same epistemic values across the different complex systems explored, whether biological, physical, or social. These skills involve the ability to recognize a variety of systems — including physical systems like Bénard's cells, chemical systems such as the Oscillating Reaction, biological systems like flocking behaviour in animals, and social systems such as segregation — as ***valuable prototypes*** of complex systems whose investigation requires a holistic and ecosystemic approach. Valuing these models as prototypes **means *appropriate the meaning and the value of the perspective of***

	complexity and turn it into a "way of thinking and acting for sustainability". These skills imply the development of the Value Building Attitude to question a "Laplacian world view" and accept the mechanistic values as valid only under some assumptions and not as "natural" or "true in absolute" and have the courage to trust complexity as a way to address (or "dance with") climate change issues and challenges. This can go together with the development of the attitude to be aware of and care for the interconnectedness between parts (typical of complex systems) and therefore their own and others' relationship with nature.

Scientific Inquiring Objectives	
*Please select the **knowledge** objectives covered in the activity*	- Identify the scientific core ideas and principles of CC and scientific rigor - Understand CC impacts and its sources - Understand the multidisciplinary nature of CC knowledge - Analyze the interactions within climate systems to identify factors contributing to their complexity • Know the scientific core ideas and principles of the science of complex systems, with a special emphasis of their role in CC • Know the forms of uncertainties involved in CC, (for example, by distinguishing between epistemic, aleatoric, and reflexive uncertainty) and know how science can contribute to dealing with them • Other:
*Please select the **skills** objectives covered in the activity*	• Apply scientific reasoning and methods • Explain climate phenomena scientifically - Identify climate-related questions and problems - Identify the disciplinary knowledge and skills involved in dealing with a CC problem and the need to cross disciplinary boundaries - Analyze climate change in relation to other challenges • Apply concepts of the science of complexity to frame CC problems • Think exploratorily, creatively, critically, and systemically

	- Other:
*Please select the **attitudinal** objectives covered in the activity*	• <u>Be willing to learn and keep learning</u> • <u>Show interest in and care about the impacts of action</u> • <u>Aim to understand and seek reliable science</u> • <u>Embrace complexity and uncertainty</u> - Embrace interdisciplinarity and accept the challenge to inhabit boundary zones - Other:
Comments on how the activity can contribute to pursue the learning objectives	The <u>Scientific Inquiring Knowledge</u> objectives are pursued in the activity by guiding the students to ***know*** and ***understand*** the following concepts of the science of complex systems: - irreducibility; - multiplicity; - circular relationship between the whole and the parts; - emergent property: unpredictable, at the level of the constituent elements, collective behaviour, meaning self-organization emerging from microscopic dynamics; - instability as an opportunity for new 'robust' structures to emerge; - uncertainty as unpredictability and sensitive dependence on initial conditions. This knowledge of the basic concepts of complexity is the basis for developing <u>Scientific Inquiring Skills</u>, that is, being able to: - ***build*** *systemic thinking*; - ***identify,*** in each of the considered models — drawn from different fields such as biological, physical, or social sciences — the result of a *framing process* resulting in a 'well-defined problem' where: ● the phenomenon is modelled to occur on two different space-time scales (microscopic and macroscopic); ● the two space-time scales represent two different levels of description; ● the two space-time scales (levels of description) “dialogue” among them in a back-and-forth dynamics, through the 'cooperation between individual elements (molecules, birds, agents,…)', an emergent phenomenon that is completely unexpected and not 'dictated from above'. These skills imply the development of <u>Scientific Inquiring Attitudes</u> such as: - ***Accepting*** the limit of validity of a scientific theory as part of the process of ***understanding and seeking reliable scienc***e; - ***Embracing complexity and uncertainty*** as part of scientific rigor and scientific capacity to address climate change issues; - ***Embody scientific thinking*** as a way to navigate the social, political, cultural, and environmental complexity of the

	contemporary era. More specifically, the activity can provide the scientific background to develop awareness that: - Even though a sustainability problem is inherently complex (and, as such, it cannot be linearised and oversimplified), patterns can be recognized and new forms of order emerge from disequilibrium; - Individual ***action*** can influence (with positive, neutral and negative results) global emergent properties on a different time-space scale than the local scale where the action takes place (development of ***active hope***); - There are connections and interactions between natural events and human ***actions***; - The short- and long-term impact of personal ***actions*** on others and the planet also depends on the individual-collective interaction (development of ***active hope***).

Envisioning Objectives	
*Please select the **knowledge** objectives covered in the activity*	- Recognize the multidisciplinary nature of CC future scenarios - Understand the current hegemonies - Understand the consequences of change and lack of change • Understand CC uncertainties and risks in futures thinking - Understand how the past events and choices affect the present and future • Recognize the temporal model and the evolution process involved in the phenomenon - Other:
*Please select the **skills** objectives covered in the activity*	• Think critically, creatively, and with a future-oriented perspective - Develop imagination skills • Develop skills in CC scenarios building - Evaluate the effects of human actions - Generate and evaluate ideas collaboratively - Link disciplines - Other:
*Please select the **attitudinal** objectives covered in the activity*	• Have the courage and willingness to imagine alternative futures - Have the courage to question current attitudes and solutions - Be willing to discontinue unsustainable practices - Appreciate the aesthetic values of the environment and envisioned future

	- Respect others' creativity - Respect different disciplines and embrace interdisciplinarity - Other:
Comments on how the activity can contribute to pursue the learning objectives	The Envisioning Knowledge objectives are pursued in the activity by guiding the students to know, ***recognise*** and ***understand***, in each of the considered models — drawn from different fields such as biological, physical, or social sciences —, their temporal structure: - the predictability, at a macro space-time scale, of the emergence of 'spontaneous organization' as a consequence of the collective behavior of a large number of elements; - the unpredictability of an event that is a random event at local level (contingency) (for example in the Bénard's cells the rotation direction of the molecules in their convective motion and the existence of a "bifurcation point": the "choice" of the rotation direction for the molecule is random (contingency) ; similar instances of local contingency can be observed in the sudden appearance of a predator bird within a flock or the unexpected presence of an obstacle along the path of an ant colony…); - the adaptability of the system, at macro level, to the local contingencies, through the creation of robust macro-structures that persist over time, well beyond the timescale of individual local interactions, and that can recover after perturbations. - the role of changing boundary conditions where variations in the system's context allow for observing how stable structures adapt, shift, or give rise to different final configurations at the macro scale. This knowledge on the temporal structure provides a conceptual frame to develop Envisioning skills, needed to think critically and imagine alternative sustainable futures. In particular, each of the considered models, can *become the prototype* to appropriate of a form of temporality where bifurcations (possible FUTURES), the role of uncertainty and contingency, the role of "rumor" open possible alternatives and challenge the linear, deterministic temporal view of classical science. These skills imply the development of Envisioning Attitudes needed to ***accept*** new forms of temporality that differ from the Newtonian one, use futures scenarios as a horizon to get oriented in the present, and value different possibilities as opportunities for change and for promoting sustainability.

Acting Objectives

Please select the ***knowledge*** *objectives covered in the activity*	- Define and prioritize CC mitigation and adaptation - Identify the relevant policies and stakeholders to address CC issues - Understand the structures within the society, its functionalities and capabilities • Other: Understand the mechanism of Individual-collective interaction for change
Please select the ***skills*** *objectives covered in the activity*	• Implement CC actions considering possible future scenarios - Implement CC actions considering different stakeholders - Implement CC actions considering the different dimensions of sustainability (environmental, social, economic) - Engage in active problem-solving to address climate change challenges - Work collaboratively - Enable mitigation and adaptation action - Articulate directions effectively - Communicate effectively • Think globally and locally • Consider the context and environment when taking action - Other:
Please select the ***attitudinal*** *objectives covered in the activity*	- Be willing to act in line with environmental, social and economic values • Have the courage to change - Take accountability and demand political accountability - Aim for action that is just and equal • Commit to facing the challenges and opportunities of climate change - Be willing to engage with others - Appreciate global and local perspectives Act with empathy and sensitivity - Other:
Comments on how the activity can contribute to pursue the learning objectives	The Acting Knowledge objective is pursued in the activity by guiding the students to know, ***recognise*** and ***understand*** the interaction between individual (micro-local level) and collective (macro-global level) in the dynamic of disturbing the equilibrium and the emergence of new patterns.

	This knowledge about the dynamics between the micro-local and macro-global levels in each of the considered phenomena provides a conceptual frame to develop the Acting skills of thinking and acting globally, thinking and acting locally, and considering the context in which interactions occur. These skills imply the development of Acting Attitudes needed to take the trust and the courage to change and to belief that local actions can make the change, as vice versa, global changes affect local actions.

Assessment of learning outcomes	
Please describe how the - Climate Change **Values Building** learning outcomes are assessed	Test the acceptance of the complexity perspective by asking the students to describe a real-life situation in which the basic concepts learned in the activity can be used. Suggestion: ask the students to build the story by developing an analogy.

Please describe how a **Scientific Inquiring** learning outcomes are assessed	1. Provide the students a simple Netlogo simulation of a complex system (e.g. "the flock of birds" and/or the segregation model") not explored during the activity and ask questions to assess whether students *are able to*:
	- recognise that it is a complex system and can explain why;
	- identify the concepts of complex systems;
	- "broaden" the discourse to:
	  - assess how individual action can impact on the global and *vice versa*;
	  - assess what it means to describe the situation at a 'local' apace-time scale (at the level of individuals) and/or at a 'global' space-time scale (at the level of the entire system).

Please describe how **Envisioning** learning outcomes are assessed	Ask the students to read a text on a climate change issue in which, depending on human actions and/or choices made at an economic and political level, different scenarios arise. For each scenario ask to: - analyse and evaluate opportunities, limitations and risks; - identify the different "actors" involved and their connections; - evaluate the role played by human actions and/or political and economic choices; - evaluate the role played by the unpredictable and the uncertain; - evaluate the space-time relationship between the planning of actions and choices and the possible future scenario.
Please describe how **Acting** outcomes are assessed	Provide the students a simple Netlogo simulation of a complex system (e.g. "the flock of birds" and/or the segregation model") not explored during the activity and ask questions to assess whether students *are able to*: - reason about how the actions of individuals can contribute to the emergence of system properties and what the “mechanisms” are.

Detailed description of the activity
The activity does not deal directly with Climate Change issues but focuses on some key concepts of complex systems that are necessary for addressing major contemporary challenges in particular to be able to deal

consciously with Climate Change. Dealing with the topic of Climate Change in fact means facing an intrinsically complex system that involves many interconnected and irreducible elements and dimensions.

The activity introduces key concepts of complexity without delving into mathematical formalism. Instead, it provides a qualitative description of phenomena across various domains: physical (e.g., Bénard cells), chemical (e.g., oscillating reactions), biological (e.g., flocking behavior in birds, ant colonies, cloud formation), and social (e.g. “segregation of Shelling”).

The activity is structured around alternating interactive lectures with different types of labs (physics, chemistry, and computer labs for NetLogo simulations) to explore the key concepts of the complexity perspective.

Interactive Lecture - In search of the key concepts of complexity

The session begins with a discussion on the etymology of the words complex and complicated. It is highlighted that complicated originally refers to something that can be explained and simplified, while complex derives from a root meaning an “inseparable interweaving.”
A complex system, therefore, cannot be reduced merely to the sum of its parts without losing something essential.
The first focus is placed on the word/concept “**irreducible.**” A complex system is irreducible to the sum of its parts.
The teacher encourages discussion by asking open-ended questions such as:
"What do you think makes something complex?" or " Can you give any examples of complex systems you find in nature?"

Next, examples of complex systems found in nature are presented, such as bird flocks, ant colonies, and cloud formation.
Stimulating questions are posed to engage students in critical thinking. For example:

- Bird flocks: thousands of birds separate and reunite in a beautiful aerial dance. Is there a hierarchy? A leader guiding the rest? Or, as ornithologist Edmund Selous suggested, is there a kind of telepathy among them?
- Ant colonies: how do ants form orderly paths when heading toward a food source? What happens if they suddenly encounter an obstacle?
- Cloud formation: how do these beautiful cloud shapes form? Where does the organization come from, which we only perceive from the “right distance” and at the “right moment”? How does the seemingly chaotic motion of countless molecules result in an organized collective phenomenon? Is it due to intentional coordination?

Throughout this phase, students are encouraged to formulate hypotheses, discuss different viewpoints, and refine their understanding through peer dialogue. The teacher facilitates rather than provides direct answers, guiding students to discover key ideas like self-organization and emergence on their own.

Laboratory Session – simulation with the application NetLogo

NetLogo simulations (available in the Models Library) are carried out, following the instructions and prompts provided within each simulation.

- Flocking: this model mimics the flocking of birds (the motion also resembles that of fish schools). Flocks are not created or led by any particular leader. Each bird follows the same simple rules, and flocking behavior emerges from their local interactions.
- Ants: in this model, a colony of ants forages for food. Though each ant follows simple rules, the colony as a whole displays sophisticated, collective behavior.
- Segregation: In this model is explored the behaviour of two types of agents in a neighbourhood. The orange agents and blue agents get along with one another. But each agent wants to make sure that it lives near some of “its own.” That is, each orange agent wants to live near at least some orange agents, and

each blue agent wants to live near at least some blue agents. The simulation shows how these individual preferences ripple through the neighbourhood, leading to large-scale patterns.

During the simulations, students work in small groups, sharing observations and adjusting parameters.

Final Group Reflection

The activity concludes with a group debriefing session focused on identifying and discussing the key concepts of complexity that emerged during the simulations and discussions. This moment is essential for reinforcing learning and connecting intuitive observations to theoretical ideas.

Students shared the key concepts that emerged, which were then written on a collective poster:

The key concepts of complexity

- **MULTIPLICITY:** a system is composed of many elements in dynamic relation to one another
- **CIRCULAR RELATIONSHIP BETWEEN WHOLE AND PARTS**
- **EMERGENT PROPERTIES**: collective behaviors that cannot be predicted by analyzing individual components—self-organizing patterns that arise from microscopic dynamics and are robust to perturbations
- **CHANGES IN SPATIAL AND TEMPORAL SCALE**
- **INSTABILITY AS A DRIVER FOR THE EMERGENCE OF NEW, ROBUST STRUCTURES**
- **UNPREDICTABILITY**

The complexity perspective is synthesized in a final shared definition of complex system.

A complex system as one that:

- Is composed of **many** elements in **dynamic** interaction
- Is **open** to its environment, which provides energy, and possibly matter and information (i.e., organizational "hints")
- Exhibits **collective behaviors** that are **unpredictable** at the level of individual components: self-organizing structures that emerge from microscopic dynamics and also feedback into them.

Physics and Chemistry Laboratories - Focusing on the Self-Organization of Complex Systems, particularly Spatial and Temporal Structures

Physics Laboratory

The *Bénard's Cells* experiment was carried out to revisit and test the concepts previously discussed.

The laboratory activity illustrates, in a fairly simple way, the theory of dissipative systems (open to the environment) by studying the collective behaviour of a fluid contained in a recipient and heated from below. Under the action of heating, convective motions form within the fluid and molecules begin to move in a disordered manner from bottom to top and vice versa. The disordered movements of the individual molecules at the microscopic level cause a phenomenon at the macroscopic level: under appropriate experimental conditions (type of liquid, shape of recipient, ΔT between the two surfaces of the liquid) the ripples become regular structures. The disordered convective motions of individual molecules (microscopic level) arrange themselves (at the macroscopic level) according to regular structures of characteristic shapes: Bénard's cells.

The focus was placed on

- the circular relationship between the microscopic level (individual molecules) and the spatial order structure at the macroscopic level
- unpredictability of the rotation direction of the molecules in their convective motion and the existence of a "bifurcation point" for the molecules: the "choice" of the rotation direction for the molecule as a random event (contingency)

This activity is explained in detail in the Template "Bénard's Cells" (see below)

Chemistry Laboratory

The *Oscillating Reaction* (Belousov–Zhabotinsky – BZ) experiment was conducted to revisit and test the concepts previously discussed. This laboratory activity is a fascinating example of non-equilibrium system where the

concentration of reactants and products oscillates periodically over time. These reactions are governed by feedback mechanisms: positive feedback amplifies certain chemical processes, accelerating the production of intermediates, while negative feedback intervenes to slow down or inhibit these processes, preventing the system from reaching a stable equilibrium. The interplay between these positive and negative feedback loops creates a dynamic balance, leading to the emergence of visible oscillations in color, concentration, or other properties over time
The focus was placed on

- feedback mechanisms
- on the emergent structure, which represents a temporal order.

Interactive Lecture - A Deeper Look at the Concept of Causality in the Complexity Perspective

Once a system involves many correlated variables, the classical view of "linear" causality—where cause precedes effect, and small causes lead to small effects while large causes lead to large effects—can no longer be applied. It may even become impossible to distinguish between cause and effect.
Feedback becomes an essential element of the cause-effect relationship, understood as a circular chain where the last effect in the chain feeds back into the original cause, amplifying it (positive feedback) or dampening it (negative feedback).

Examples of feedback loops in nature were explored, using the TED lesson "Feedback in Nature" (link: *Cicli di feedback: e la natura prende il suo ritmo! | Settings*). This lesson provided insights into various natural systems where feedback mechanisms play a crucial role in maintaining balance and driving change. The discussion highlighted how feedback loops are integral to processes like climate regulation, ecological balance, and even biological rhythms.

In this phase, brainstorming sessions were conducted, and students were actively engaged through a series of thought-provoking questions. They were encouraged to explore real-world examples of feedback, discussing not only their own observations but also drawing connections to complex systems they had studied.

Additionally, the concept of feedback was applied to real-world issues such as global warming, focusing on the accelerating effects of climate change. For instance, the melting of glaciers was presented as a feedback loop where the loss of ice reduces the Earth's albedo (reflectivity), leading to more heat absorption by the oceans and further acceleration of ice melt. This process exemplifies a positive feedback loop, where the effects continuously reinforce the initial cause, intensifying the overall impact.

Worksheets
Supporting materials can be found in CLAUDI.

Example 2 - Bénard’s Cells

General Information	
Title of activity:	**Laboratory activity: Bénard’s Cells**
Estimated duration:	1 hour: execution of the experiment 2 hours: analysis of the experiment 2 hours: Netlogo simulation
Target group:	Grade 11
Related disciplines:	**Physics**

Contextual Information	
Reference to the hub:	Italian HUB
Author(s) of the activity:	Paola Fantini, Veronica Ilari
Schools/contexts where the activity was developed:	Scientific high school “Liceo Statale A. Einstein”, Rimini
Schools/contexts where the activity was implemented:	Scientific high school “Liceo Statale A. Einstein”, Rimini

Topic of Activity	
Fundamental scientific ideas of Climate Change	The activity brings into focus, from a physical point of view, some important concepts typical of complex systems such as: - irreducibility; - multiplicity; - circular relationship between the whole and the parts; - emergent property: unpredictable, at the level of the constituent elements, collective behaviour, meaning self-organization emerging from microscopic dynamics; - need to change the space-time scale in the description of the phenomenon; - instability as an opportunity for new 'robust' structures to emerge; - unpredictability. The activity does not deal directly with Climate Change issues but focuses on some fundamental concepts of complex systems; these

	concepts are necessary to be able to deal with Climate Change as an inherently complex system involving many interconnected and irreducible elements and dimensions.

Values Building Objectives	
*Please select the **knowledge** objectives covered in the activity*	- Recognize multiple worldviews and cultural differences - Recognize the influence of social, economic, and environmental issues to values - Recognize the human and more-than-human interconnectedness - Know ethical principles, justice, and sustainable values - Know principles of nature conservation/protection • Recognize the meaning and the value of the perspective of complexity to think and act for sustainability - Other:
*Please select the **skills** objectives covered in the activity*	- Make ethical decisions and take action - Recognize one's own and others' values, and their consequent impacts on systems - Develop empathy - Assess personal values in relation to climate values • Be willing to recognize and analyze the connectedness of social, economic, and environmental systems to identify holistic solutions - Facilitate discussions acknowledging diverse worldviews - Promote constructive dialogue • Other: be able to appropriate the meaning and the value of the perspective of complexity and to turn it into a "way of thinking and acting for sustainability"
*Please select the **attitudinal** objectives covered in the activity*	- Commit to valuing and protecting nature - Respect and embrace cultural and environmental diversity - Show deep concern for the social and environmental impacts of climate change - Prioritize equitable and sustainable solutions • Be aware of and care for one's own and others' relationship with nature and its protection • Other: Accept the values of the perspective of

	<u>complexity as needed to think and act for sustainability</u>
Comments on how the activity can contribute to pursue the learning objectives	The <u>Value Building Knowledge</u> objective is pursued in the activity by guiding the students to ***know the basic epistemic values of the perspective of complexity*** *(in contrast to the mechanistic linear perspective): the values of systemic non-linear connections, the value of contingency, probabilistic thinking, the value of multi-dimensionality and of the circular relationship between the dimensions, the values of recognising links between what appears fragmented or separate (holistic view).* This knowledge of the complexity epistemic values is the basis for developing <u>Values Building Skills</u>, such as being able to recognise the physical model of Bénard's cells as a ***valuable prototype*** of a complex system whose investigation implies a holistic and ecosystemic approach. To value Bernard's cells as a prototype means to ***appropriate the meaning and the value of the perspective of complexity and turn it into a "way of thinking and acting for sustainability".*** These skills imply the development of the <u>Value Building Attitude</u> to question a "Laplacian world view" and accept the mechanistic values as valid only under some assumptions and not as "natural" or "true in absolute" and have the courage to trust complexity as a way to address (or "dance with") climate change issues and challenges. This can go together with the development of the attitude to be aware of and care for the interconnectedness between parts (typical of complex systems) and therefore their own and others' relationship with nature.

Scientific Inquiring Objectives	
Please select the ***knowledge*** *objectives covered in the activity*	- Identify the scientific core ideas and principles of CC and scientific rigor - Understand CC impacts and its sources - Understand the multidisciplinary nature of CC knowledge - Analyze the interactions within climate systems to identify factors contributing to their complexity • <u>Know the scientific core ideas and principles of the science of complex systems, with a special emphasis on their role in CC</u> • <u>Know the forms of uncertainties involved in CC, (for example, by distinguishing between epistemic, ontic and aleatoric, and reflexive uncertainty) and know how science can contribute to dealing with them</u>

	• Other:
*Please select the **skills** objectives covered in the activity*	- Apply scientific reasoning and methods • Explain climate phenomena scientifically - Identify climate-related questions and problems - Identify the disciplinary knowledge and skills involved in dealing with a CC problem and the need to cross disciplinary boundaries - Analyze climate change in relation to other challenges • Apply concepts of the science of complexity to frame CC problems • Think exploratorily, creatively, critically, and systemically - Other:
*Please select the **attitudinal** objectives covered in the activity*	• Be willing to learn and keep learning • Show interest in and care about the impacts of action • Aim to understand and seek reliable science • Embrace complexity and uncertainty - Embrace interdisciplinarity and accept the challenge to inhabit boundary zones - Other:
Comments on how the activity can contribute to pursue the learning objectives	The Scientific Inquiring Knowledge objectives are pursued in the activity by guiding the students to ***know*** and ***understand*** the following concepts of the science of complex systems: - irreducibility; - multiplicity; - circular relationship between the whole and the parts; - emergent property: unpredictable, at the level of the constituent elements, collective behaviour, meaning self-organization emerging from microscopic dynamics; - instability as an opportunity for new 'robust' structures to emerge; - uncertainty as unpredictability and sensitive dependence on initial conditions. This knowledge of the basic concepts of complexity is the basis for developing Scientific Inquiring Skills, that is, being able to: - ***build*** *systemic thinking;*

	- ***identify,*** in the physical model of Bénard's cells, the result of a *framing process* resulting in a 'well-defined physical problem' where: ● the phenomenon is modelled to occur on two different space-time scales (microscopic and macroscopic); ● the two space-time scales represent two different levels of description; ● the two space scales (levels of description) “dialogue” among them in a back-and-forth dynamics, through the 'cooperation between molecules' that form Bénard’s cells, an emergent phenomenon that is completely unexpected and not 'dictated from above'. These skills imply the development of Scientific Inquiring Attitudes such as: - ***Accepting*** the limit of validity of a scientific theory as part of the process of ***understanding and seeking reliable scienc***e; - ***Embracing complexity and uncertainty*** as part of scientific rigor and scientific capacity to address climate change issues; - ***Embody scientific thinking*** as a way to navigate the social, political, cultural, and environmental complexity of the contemporary era. More specifically, the activity can provide the scientific background to develop awareness that: - Even though a sustainability problem is inherently complex (and, as such, it cannot be linearised and oversimplified), patterns can be recognized and new forms of order emerge from disequilibrium; - Individual ***action*** can influence (with positive, neutral and negative results) global emergent properties on a different time-space scale than the local scale where the action takes place (development of ***active hope***); - There are connections and interactions between natural events and human ***actions***; - The short- and long-term impact of personal ***actions*** on others and the planet also depends on the individual-collective interaction (development of ***active hope***).

Envisioning Objectives	
*Please select the **knowledge** objectives covered in the activity*	- Recognize the multidisciplinary nature of CC future scenarios - Understand the current hegemonies - Understand the consequences of change and lack of change ● Understand CC uncertainties and risks in futures thinking - Understand how the past events and choices affect the present and future

	• Recognize the temporal model and the evolution process involved in the phenomenon • Other:
*Please select the **skills** objectives covered in the activity*	• Think critically, creatively, and with a future-oriented perspective - Develop imagination skills • Develop skills in CC scenarios building - Evaluate the effects of human actions - Generate and evaluate ideas collaboratively - Link disciplines - Other:
*Please select the **attitudinal** objectives covered in the activity*	• Have the courage and willingness to imagine alternative futures - Have the courage to question current attitudes and solutions - Be willing to discontinue unsustainable practices - Appreciate the aesthetic values of the environment and envisioned future - Respect others' creativity - Respect different disciplines and embrace interdisciplinarity - Other:
Comments on how the activity can contribute to pursue the learning objectives	The Envisioning Knowledge objectives are pursued in the activity by guiding the students to know, ***recognise*** and ***understand***, in the physical model of Bénard's cells, its temporal structure: - the predictability, at the macro space-time scale, of the creation of 'spontaneous organisation' as a consequence of the collective behaviour of a large number of molecules; - the unpredictability of the rotation direction of the molecules in their convective motion and the existence of a "bifurcation point" for the molecules (See Activity description, figg.1-2). The "choice" of the rotation direction for the molecule is random and represents a random event (contingency) (fig. 2) - the adaptability of the system, at macro level, to the local contingency by the creation of robust macro-structures, that last much longer than the time between two molecular collisions and return to form after a perturbation of the system. - Changes in the boundary conditions and in the lab settings (e.g changes of the kind of oil, the container dimension, the liquid hight) allows one to "play" between changes and stable structures and observe different possible final configurations at the macro scale.

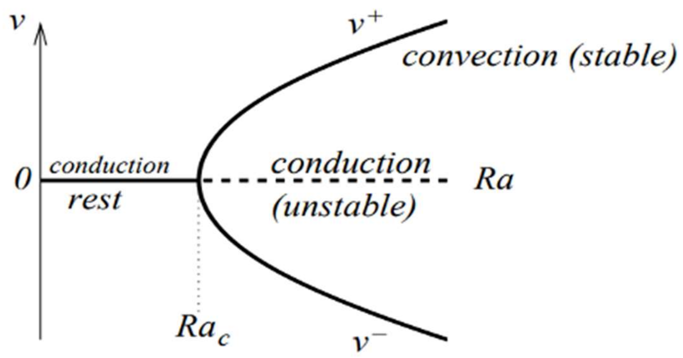


Fig. 2 "If a non-equilibrium constraint is applied (in this case by providing heat-mode energy) the system shows, at the bifurcation point, a spontaneous transition to a new state (with macroscopically ordered structures). The “choice” of the direction of rotation is related to a contingency, not predictable a priori." (Ilari, 2024)

This knowledge on the temporal structure of Bénard's cells provides a conceptual frame to develop Envisioning skills, needed to think critically and imagine alternative sustainable futures. In particular, Bénard's cells can *become the prototype* to appropriate of a form of temporality where bifurcations (possible FUTURES), the role of uncertainty and contingency, the role of “rumor” open possible alternatives and challenge the linear, deterministic temporal view of classical science.
These skills imply the development of Envisioning Attitudes needed to ***accept*** new forms of temporality that differ from the Newtonian one, use futures scenarios as a horizon to get oriented in the present, and value different possibilities as opportunities for change and for promoting sustainability.

Acting Objectives	
*Please select the **knowledge** objectives covered in the activity*	- Define and prioritize CC mitigation and adaptation - Identify the relevant policies and stakeholders to address CC issues - Understand the structures within the society, its functionalities and capabilities • Other: Understand the mechanism of Individual-collective interaction for change

*Please select the **skills** objectives covered in the activity*	• <u>Implement CC actions considering possible future scenarios</u> - Implement CC actions considering different stakeholders - Implement CC actions considering the different dimensions of sustainability (environmental, social, economic) - Engage in active problem-solving to address climate change challenges - Work collaboratively - Enable mitigation and adaptation action - Articulate directions effectively - Communicate effectively • <u>Think globally and locally</u> • <u>Consider the context and environment when taking action</u> • Other:
*Please select the **attitudinal** objectives covered in the activity*	- Be willing to act in line with environmental, social and economic values • <u>Have the courage to change</u> - Take accountability and demand political accountability - Aim for action that is just and equal • <u>Commit to facing the challenges and opportunities of climate change</u> - Be willing to engage with others - Appreciate global and local perspectives Act with empathy and sensitivity - Other:
Comments on how the activity can contribute to pursue the learning objectives	The <u>Acting Knowledge</u> objective is pursued in the activity by guiding the students to know, ***recognise*** and ***understand*** the interaction between individual (micro-local level) and collective (macro-global level) in the dynamic of disturbing the equilibrium and the emergence of new patterns. This knowledge on the dynamics between micro-local and macro-global level of Bénard's cells provides a conceptual frame to develop <u>Acting skill</u> of thinking-acting globally and thinking-acting locally, as well as the skill of considering the context in which the interactions occur (boundary conditions of the phenomenon). These skills imply the development of <u>Acting Attitudes</u> needed to take the trust and the courage to change and to believe that local actions can make the change, as vice versa, global changes affect local actions.

Assessment of learning outcomes	
Please describe how the - Climate Change **Values Building** learning outcomes are assessed	Test the acceptance of the complexity perspective by asking students to describe an everyday situation in which the values of systemic non-linear connections, of contingency, of multi-dimensionality and of the circular relationship between the dimensions can be used. Suggestion: ask the students to build the story by developing an analogy.
Please describe how a **Scientific Inquiring** learning outcomes are assessed	Ask students to produce an individual laboratory report on the execution of the experiment, addressing the following points: • the relationship between boundary conditions or experimental parameters (e.g., type of oil, container size, liquid height) and the organized cell structure exploring the balance between change and stability; • the interaction between the two spatial scales (levels of description) in a back-and-forth dynamic, through the cooperation of molecules that leads to the formation of Bénard cells — an emergent phenomenon that is entirely unexpected and not imposed from above
Please describe how **Envisioning** learning outcomes are assessed	Ask students to watch a simulation of the Bénard's cell experiment and to identify and describe the temporal structure within the physical model. Ask students to reflect on aspects such as: • The degree to which, at the macroscopic space-time scale, the emergence of spontaneous organization can be considered predictable as a result of the collective behavior of a large number of molecules; • The unpredictability of the rotation direction of molecules in their convective motion, and the role played by the existence of a bifurcation point at the microscopic level; • The system's ability to adapt, at the macroscopic level, to local contingencies (random rotation direction for the molecule) by forming robust macrostructures that last significantly longer than the time between individual molecular collisions, and that re-form after perturbations.
Please describe how **Acting** outcomes are assessed	Ask students to describe a situation in which the interaction between individual dynamics (micro level within the Bénard's cell model) and collective behaviour (the macro within the Benard's cell model) becomes evident. Ask students to reflect on how individual actions contribute to the emergence of collective patterns, and how, in turn, these collective structures can influence individual behaviours.

Detailed description of the activity
The activity does not deal directly with Climate Change issues but focuses on some fundamental concepts of complex systems that are necessary to be able to deal consciously with Climate Change. Dealing with the topic

of Climate Change in fact means facing an intrinsically complex system that involves many interconnected and irreducible elements and dimensions.
The laboratory activity illustrates, in a fairly simple way, the theory of dissipative systems by studying the collective behaviour of a fluid contained in a recipient and heated from below. Under the action of heating, convective motions form within the fluid and molecules begin to move in a disordered manner from bottom to top and vice versa. The disordered movements of the individual molecules at the microscopic level cause a phenomenon at the macroscopic level: at a certain ΔT between the surface of the liquid in contact with the heat source and the free surface, a more or less pronounced rippling occurs. Under appropriate experimental conditions (type of liquid, shape of recipient, ΔT between the two surfaces of the liquid) the ripples become regular structures; the disordered convective motions of individual molecules (microscopic level) arrange themselves (at the macroscopic level) according to regular structures of characteristic shapes: Bénard’s cells. A completely unexpected 'cooperation between molecules' is established at the macroscopic level despite the disordered movements of individual molecules (microscopic level).
Providing heat to a system does not always mean an increase in disorder and consequently a loss of organisation.
This process is analogous to that which governs the formation of certain cloud structures associated with ascending and descending thermal currents and also resulting from unexpected molecular cooperation. (G. Zanarini, Finestre sulla complessità, Editoriale Scienza).

Realisation of the experience

Material:
- gas cooker
- pyrex glass containers of different diameters (10-15 cm) and height approx. 2 cm
- thermometer consisting of a probe with thermocouple connected to a digital multimeter
- olive oil; silicone oil; talcum powder; powdered coloured pigments

Procedure:
Divide the students into groups. To some groups provide olive oil and talcum powder, to others silicone oil and pigments.
Each group should:
Place the Pyrex glass container on top of the stone slab for heat diffusion, pour in the liquid (a few mm), add talcum powder to the olive oil and pigments to the silicon oil so that a thin patina is created to show the cells.
Start heating the liquid until it reaches a temperature of about 120° C on the bottom layer of oil in contact with the pan. Turn off the cooker so as not to exceed the temperature and give rise to particularly turbulent motions.
Observe on the surface of the liquid the formation of characteristic cells whose shape tends to be hexagonal.
Observe that if the system is disturbed with a teaspoon, thus creating disorder, the cells will form again after a few seconds.
Change container size and repeat test. Change the thickness of the liquid and repeat the test. Write down on a table under which conditions (ΔT, container size, liquid thickness) the cells were formed and describe them for each test performed.
Compare the groups: Construct a single table relating the formation of the cells, their shape and size to the ΔT, the container size, the thickness of the liquid.

At the end of the activity, have the participants explore a simple netlogo simulation of a complex system (e.g. "the flock of birds" and/or the segregation model") to recognize and identify the concepts of the complex systems encountered during the activity.
Make them reflect on

- which 'elements' are interacting (molecules for Bénard's cells, birds or individuals for simulations); - how the action of the individual can impact on the global and vice versa; - what it means to describe a situation at a 'local' space-time scale (at the level of the individual elements) and/or at a 'global' space-time scale (at the level of the whole system).

Worksheets
Supporting materials can be found in CLAUDI.

Tips for designing the activities and their evaluation

Start-up the process and establishment of the management and coordination structure

Start-up phase (management and coordination)

Organization of a calendar of informal meetings (if needed, *with the support of an external stakeholder expert in project design and in science education*) in order to:

- (relational level) identity the group of teachers who can be interested in dealing with the themes of complexity; establish, in the group of teachers, who can play the role of coordinator, facilitator, implementer…; map teachers' motivations, interests and areas of disciplinary comfort zones;
- (epistemic-cognitive level) map preliminary ideas about the topics, the disciplinary knowledge involved, the knowledge present in the group and the knowledge that has to be developed or imported (in terms of experts that can provide an external support);
- (institutional level) map possible contexts (curricular, extra-curricular, spaces …) and possible institutional barriers that should be addressed
- (socio-cultural level) share reasons why students should be involved in the activity/project and why the school should invest time and personnel resources on the project.

Study of existing materials

Organization of the "scientific" agenda (if needed, *with the support of an external stakeholder expert in project design and in science education*) to analyse the template and select further materials and organize a process of studying. This phase can be done individually or in group. In the latter case, it should include both moments of personal study and moments of co-learning. Suggestions for this phase are:

- (relational level) to download the materials and search for further scientific and educational materials.
- (epistemic-cognitive level) to study the materials to develop disciplinary, but also to develop knowledge on science education research on students' difficulties.
- (socio-cultural level) to address, systematically, questions about what CLIMADEMY competences the activities intend to develop and build a strategy on how to pursue them with the activity.

Analysis of the activity

Organization of the "scientific" agenda (if needed, *with the support of an external stakeholder expert in project design and in science education*) to analyse the materials. This phase can be carried out in parallel to the previous one. It should include both moments of personal work and moments of co-learning. Suggestions for this phase are:

- (relational level) to build small working groups, taking care of creating a safe boundary safety, where different competences are valued to analyse the materials, identify eventual boundary objects and analyse them.
- (epistemic-cognitive level) to organize individual or in-group moments aimed to deeply analyse the materials, unpack their educational potential (for this phase, follow the guidelines of Section 3.3- A); organize team group to try out the lab experiments and/or to analyse the simulations; discuss on the difficulties students may encounter both in carrying out the activity and in fine-tuning the concepts involved.
- (socio-cultural level) to organize individual or in-group moments to analyse the contribution of the activities to the development of CLIMADEMY competences; identify the competences of the CLIMADEMY framework can be developed through the activities;
  discuss on the learning outcomes and unpack how they can be pursed thought the activity and evaluated.

Design of the activity and content creation

Revise the activity and the assessment tools, by:
(epistemic-cognitive level) taking care of the suggestions from MER and CoRE (Section 3.3 – A; Section 3.3 – E; Annex B);
(relational level) taking care of the dynamics among teachers (mainly if they are from different disciplines)(Section 3.3 – C);
(pedagogical level) choosing the learning environment and the forms of participation you intend to create (Section 3.3 – B);
(socio-cultural level) staying coherent with CLIMADEMY competence framework (Section 3.3 – D; Annex A).

Implement the activity by taking note of the difficulties, the criticalities and the potential at epistemic-cognitive, relational, pedagogical, socio-cultural and institutional level.

A posteriori reflections on the activity and re-design

Analyse the activity carried out from an educational point of view
Examples of questions to guide the reasoning:

- Was the activity important for the students? Why?
- What competences did this activity develop?
- Did the activity meet the expectations? If not, what happened that was not expected?
- Were any difficulties encountered by the students and/or teachers? if so, which ones?
- What was learned?
- How was the dynamics of co-design and/or co-teaching among the teachers?

- Did the activity meet any difficulty at institutional level?
- Did the activity have any implication at institutional level?
-

Redesigning the activity

Examples of questions to guide reasoning:

What changes would you make to the activity?