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Pedagogical model for teacher education on climate change within the European CLIMADEMY project

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“Every atom that makes up you and me has been recycled
throughout the universe and throughout Earth
on its cosmic journey.
Yes, we are stardust,
but we are also intimately connected to everything
that has ever lived on Earth
and
to the very rocks we walk on,
water we swim in,
and air we breathe”

DISCLAIMER

The views and opinions expressed in this publication are the authors' sole responsibility and do not necessarily reflect the views of the European Commission.
This thesis contains original, unpublished work except where clearly indicated otherwise. It builds upon the work of the teams involved in the CLIMADEMY project, the team of the Italian CLIMADEMY hub and the physics educational research group of the University of Bologna.
Acknowledgement of previously published material and others' work has been made through appropriate citation, quotation, or both.

Table of Contents

Abstract
Acronyms

Introduction

Chapter 1 - The context and the CLIMADEMY project

Chapter 2 - Study on pre-service and in-service needs for teaching Climate Change

Chapter 3 - CLIMADEMY Pedagogical Model

Chapter 4 – The Pedagogical Model in Practice

Conclusion

Acknowledgements

References & Sitography

Appendix

Abstract

The present work is framed within CLIMADEMY (Climate Change Teachers' Academy), a three-year Erasmus+ project started in June 2022, coordinated by the University of Crete, involving six further partners and two associated partners (https://climademy.eu/). The CLIMADEMY project is developing a comprehensive training framework for in-service and pre-service teachers to support them in understanding Climate Change drivers and impacts, mitigation and adaptation actions, and to promote their efficiency in teaching and learning about Climate Change. The project is part of a new Erasmus + action whose scope is to build teacher education European networks and share novel and efficient teaching methodologies to regenerate the education of the next generation of European citizens. This work thesis contributed to work package three of the project. Specifically, it contributed to developing the pedagogical model for teacher education on Climate Change to be used as a reference framework in the training activities. This model is supposed to play two roles in teacher education. Firstly, the pedagogical model is expected to orient the partners and the teacher trainers to convey, besides the scientific contents, tools and knowledge developed in science education research. Secondly, the pedagogical model is expected to provide the "pedagogical identity" to the activities on Climate Change designed or adapted within CLIMADEMY in the hubs. In this thesis, I present a study of teachers' needs in teaching Climate Change using three different data collection contexts. Then, I illustrate the developing process of the pedagogical model, underlining my role in analysing the research theoretical frameworks, extracting the key messages to convey to teachers, and designing a template to present, discuss or analyse training activities. Finally, I describe two activities for teacher education on Climate Change and illustrate how these activities can exemplify the pedagogical model.

Sommario

Il presente lavoro è collocato nel progetto CLIMADEMY (Climate Change Teachers' Academy), un progetto Erasmus+ triennale avviato nel giugno 2022, coordinato dall'Università di Creta, che coinvolge ulteriori sei partner e due partner associati (https://climademy.eu/). Il progetto CLIMADEMY sta sviluppando un quadro di formazione completo per gli insegnanti in servizio e in formazione per supportarli nella comprensione dei fattori e degli impatti ai cambiamenti climatici, delle azioni di mitigazione e adattamento e per promuovere la loro efficienza nell'insegnamento e nell'apprendimento dei cambiamenti climatici. Il progetto fa parte di una nuova azione Erasmus+ il cui scopo è costruire reti europee per la formazione degli insegnanti e condividere metodologie didattiche nuove ed efficaci per rigenerare l'istruzione dei cittadini europei della prossima generazione. Questa tesi ha contribuito al pacchetto di lavoro tre del progetto. In particolare, ha contribuito a sviluppare il modello pedagogico per la formazione degli insegnanti sui cambiamenti climatici da utilizzare come quadro di riferimento nelle attività di formazione degli insegnanti. In particolare, questo modello avrà due ruoli nella formazione degli insegnanti. In primo luogo, il modello pedagogico dovrebbe orientare i partner e i formatori a trasmettere, oltre ai contenuti scientifici, gli strumenti e le conoscenze sviluppate nella ricerca sull'educazione scientifica. In secondo luogo, ci si aspetta che il modello pedagogico fornisca una "identità pedagogica" alle attività sul cambiamento climatico progettate o adattate all'interno degli hub di CLIMADEMY. In questa tesi, presento uno studio sulle esigenze degli insegnanti nell'insegnamento del cambiamento climatico utilizzando tre diversi contesti di raccolta dati. Successivamente, illustrerò il processo di sviluppo del modello pedagogico, sottolineando il mio ruolo nell'analisi dei quadri teorici di ricerca, nell'estrazione dei messaggi chiave da trasmettere agli insegnanti e nella progettazione di un modello per presentare, discutere o analizzare le attività di formazione. Infine, descrivo due attività per la formazione degli insegnanti sul cambiamento climatico e illustrerò come queste attività possano aiutare a spiegare il modello pedagogico.

Acronyms

CC: Climate Change

CCE: Climate Change Education

ERTE: Educational Reconstruction for Teacher Education

IPCC: Intergovernmental Panel on Climate Change

MER: Model of Educational Reconstruction

PCK: Pedagogical Content Knowledge

SL: Scientific literacy

SRPs-TE: Study and Research Paths for Teacher Education

SSI: Socio Scientific-Issue

UNFCCC: United Nations Framework Convention on Climate Change

WP: Work Package

Introduction

The rapid Climate Change observed during the last century is attributed to human activities (IPCC, 2021). Climate Change (CC) critically impacts the natural environment and human society, threatening the biodiversity and survival of ecosystems on one hand and affecting health and economies on the other. Mitigation of Climate Change poses one of the major challenges to modern society. The efforts of different stakeholders through collective and individual actions are needed in order to meet the Paris Agreement. Europe aims to achieve climate neutrality by 2050, also through Green Deal projects supported by Horizon 2020.

One key to achieving Green Deal objectives is to educate the new generations on Climate Change. Besides learning about the causes and consequences of CC, students are supposed to be educated on how to mitigate CC and how human society can adapt to it.

In-service teachers and pre-service teachers are key stakeholders in this educational innovation. However, teachers should be trained in order to teach students about the fundamental ideas and key concepts of such a complex topic as Climate Change, and moreover, guide students in developing several sustainability competences. Educational research findings underlined the importance of teachers' professional development both in terms of scientific content knowledge and of up-to-date educational methods to approach these topics, e.g., by implementing inquiry-based teaching. The CLIMADEMY[1] project responds to the challenge of equipping in-service and pre-service teachers with the necessary subject-matter knowledge and teaching strategies by developing a comprehensive training framework. Furthermore, this project aims to support the establishment of communities of practices and the activities of teacher educators as informal mentors for their colleagues. Experienced secondary school teachers are involved in this project as co-designers of educational materials, activities and models for teaching that will be openly available through an online platform connected to four national hubs (CLAUDI[2] platform).

This work thesis contributes to this project in developing a pedagogical model for teacher education. This model was developed in the work package three (WP3) of the project, led

[1] Climate Change Teachers' Academy. Erasmus 2027 programme. Call: ERASMUS-EDU-2021-PEX-TEACH-ACA. Project ID: 101056066. Agency: EUROPEAN EDUCATION AND CULTURE EXECUTIVE AGENCY (EACEA). Website: https://climademy.eu/

[2] https://claudi.chemistry.uoc.gr/

by the educational group of the University of Bologna, with the collaboration of all the other partners. However, this thesis work went beyond the specific tasks of the WP3, and I was guided in my study by the following research questions:

RQ1. "What are the pre-service and in-service teachers' needs about a teacher education on CC?"
RQ2. "What is the nature and depth of these needs?"
RQ3. "How can teachers' needs be considered by designing a pedagogical model for teacher education on CC?"

The thesis is articulated in four chapters and the conclusion.

In the first chapter, the state-of-art of Climate Change Education and the CLIMADEMY project is presented.
In the second chapter, the study on pre-service and in-service teachers' needs in teaching CC is illustrated. The latter study is built on three different data collection contexts. The results from this study were compared and triangulated with the research findings, leading to the identification of four major challenges. If these challenges are addressed, the teachers' needs in teaching CC can be met.
In the third chapter, the pedagogical model is presented, along with a deep analysis of the theoretical frameworks employed during its co-designing and a selection of the main messages to deliver in teacher education on CC.
Finally, in the fourth chapter, the template to use the designed pedagogical model in practice is presented. Then, the template is applied to selected educational resources to carry out activities on Climate Change in secondary schools and teacher education. Precisely, two prototypes of activities on CC are illustrated. The first type uses educational resources to carry out an interdisciplinarity activity on the biodiesel topic. The second type uses educational material I designed to conduct an activity using the Atlas platform.

Chapter 1 - The context and the CLIMADEMY project

1.1. Climate Change Education and Teacher Training

In 2019, the European Parliament recognised education as one of the most effective tools against Climate Change (CC):

"*Education for young people represents one of the most effective tools for combating Climate Change*" (EUROPARL, 2019).

Article 6 of the United Nations Framework Convention on Climate Change (UNFCCC) directs countries to consider education, training and public awareness as integral responses to CC. The climate crises cannot be addressed only through political agreements, green taxes and financial incentives, and solutions technologies. Existing attempts to reduce emissions through taxes or technologies have proven to be unsuccessful in inducing mitigation and adaptation, thus far at least (United Nations Task Team on Social Dimensions of Climate Change, 2011). While technological and financial policies undoubtedly have a role to play in CC, broader structural, cultural, perceptual, behavioural and ideological shifts are also necessary. In other words, transformative shifts in how we think and act and how we relate to present and future generations are necessary. This is where education has a crucial role to play in climate response (Mochizuki & Bryan, 2015).

Despite the social relevance of Climate Change Education, the topic of Climate Change is not yet broadly incorporated into school science curricula (Sharma, 2012). Many reposts highlight that there is still little emphasis on CC within science curricula (Osborne & Dillon, 2008). Dillon (2022) studied the debate about the place of CC in the curriculum in the UK. In his view, the increasing public and political awareness of the impact of CC on the world means that it is likely that in the near future, CCE will have a greater presence in science curriculum in the UK and elsewhere.

Even if CC will likely have more space in the school curriculum in the following years, Climate Change (CC) is a challenging topic to teach since it is a complex socio-scientific issue and a wicked sustainability problem. CCE demands more than the teaching of scientific content since CC cannot be dealt with as a mere scientific phenomenon.

McKeown and Hopkins (2010), for example, describe Climate Change education as comprising two parts: climate and change. “Climate”, they explain, involves the natural sciences, while “change”, or education for change, involves engaging the social sciences and humanities. For Stevenson and colleagues (2017), CCE, in essence, implies learning in the face of risk, uncertainty and rapid change. According to the latter authors, CCE involves creatively preparing children and young people for a rapidly changing, uncertain, risky and possibly dangerous future.

CCE explores mitigation and adaptation at both local and global levels (Kagawa & Selby, 2010). Encouraging and inspiring individuals to take personal action to mitigate CC is encouraged by many (O’Neill & Nicholson-Cole, 2009; Wolf & Moser, 2011). However, some warn against educational responses that end with simplistic or one-off individual actions (Robottom & Hart, 1995) since transitioning from unsustainable value and practice requires students to assume responsibility and develop the capacity to become civically engaged in collective action.

Mitigation efforts will not be enough to respond to CC, so individuals and communities will also need to adapt to future impacts that are unlikely to be avoided. Adaptation education is considered necessary to lower risk and vulnerability and build adaptive capacity and resilience (Krasny and DuBois, 2016; United Nations Educational Scientific and Cultural Organisation & United Nations Environment Programme, 2011).

Rousell & Cutter-Mackenzie-Knowles (2019) analysed existing literature from 1993 to 2014 regarding Climate Change education for children and young people. Their systematic review identifies the need for participatory, interdisciplinarity, creative and affect-driven approaches to Climate Change Education, which to date have been largely missing from the literature. Brownlee, Powell and Jeffery (2013) conclude that CCE needs to move beyond cognitive and scientific knowledge-based approaches in order to engage learners with the affective dimensions of the issue. The latter authors suggest that CCE should become more responsive to the existing beliefs, attitudes and situational contexts of specific audiences

rather than focusing on what people do not know or understand about CC.
Monroe and colleagues (2017) conducted a systematic review of the research (49 studies) in order to identify effective Climate Change Education strategies. Two themes were identified that are common to most environmental education: (1) focusing on personally relevant and meaningful information and (2) using active and engaging teaching methods.
Kagawa and Selby (2010) argue that Climate Change education requires a "social holistic learning process" that is flexible and embeds learning with action within the local community context (p.242). Classrooms should be oriented towards taking up the challenge of rethinking the world (Kagawa and Selby, 2010) and encouraging "out-of-the-box" thinking (Glasser, 2007).

As the previous review shows, CCE challenges the vision of scientific literacy and science education itself. The growing reaction of some citizens and political leaders, denying scientific knowledge about socio-scientific issues of planetary relevance, such as Climate Change, together with the diversity and multiplication of fake news and unreliable sources of information regarding the techno-scientific risks to which we are exposed daily, has served as an alert to reactivate the global commitment to scientific literacy (Nguyen and Catalan-Matamoros, 2020). The concept of scientific literacy has moved from a transmissive vision of the educational process, focused on the unilateral transmission of scientific knowledge and without a clear link to the social dimension of science (Vision I), towards a socio-cultural and situated vision of the educational process (Vision II), and finally, to a transformative vision committed to participation and emancipation (Vision III) (Valladares, 2021).

In accordance with this Vision III, teachers have a crucial role in shaping the character of the youth. In the project CLIMADEMY, the following difficulties for teaching the topic of Climate Change have been pointed (i) its interdisciplinarity nature, (ii) the complexity and multidimensionality of the phenomenon, (iii) the quick and continuous research development that requires demanding process of updating, (iv) teachers' lack of specific training on the subject, (v) lack of teaching methods to approach this topic, (vi) dispersed information on the web and (vii) difficulty to prioritise thematics.

Some of the teachers' difficulties can be related to CC as a socio-scientific issue. Studies have shown that teachers do not make the connection between science and students' everyday life since they find it difficult to relate scientific data and the social aspects of the problem, which bring uncertainty into the discussions (Evagorou 2011; Forbes and Davis 2007). Research studies suggest that science teachers find it challenging to guide student learning in SSI (Evagorou 2011; Levinson 2006), and this is mainly because teaching SSI puts a demand on science teachers to use information and knowledge from outside their scientific domains (i.e., moral, financial, ethical dilemmas) (Simonneaux and Simonneaux 2008).

Plutzer & Hannah (2018), using a nationally (USA) representative survey of 1’500 middle school and high school science teachers, showed that increased science coursework in college has modest effects on teachers’ content knowledge and on their teaching choices. Providing future teachers with a better grounding in climate science is a worthwhile but small step towards reducing the mixed messages that American students currently receive. Recent education research on current scientific topics such as Climate Change highlights the importance of teachers’ professional development both in terms of scientific content knowledge and of up-to-date educational methods to approach these topics (Blonder, 2010). However, Loucks-Horsley and colleagues (2010) point out that traditional “mass” teacher professional development projects rarely succeed as they lack attention to the individual needs of each teacher and opportunities for substantial teacher interaction and in-depth study and practice. Akerson and colleagues (2009) and Kyndt and colleagues (2016) research on teacher education reveal that teachers’ learning and professional development are better accomplished when engaging in learning activities along with their colleagues within communities of practice.

1.2 CLIMADEMY Project

The CLIMADEMY project is situated in this context and aims to supply pre-service and in-service teachers with both the necessary subject knowledge and teaching methods to address the aforementioned teachers’ difficulties.

The European Project of CLIMADEMY (CLIMAte change Teachers’ acaDEMY, Erasmus 2027 programme, Agency: EACEA, Call: ERASMUS-EDU-2021-PEX-TEACH-ACA, Project ID: 101056066, website: https://climademy.eu/) started in June 2022 and has a duration of 36 months. The University of Crete (UOC) coordinates the project and involves five further partners: the University of Bologna (UNIBO), particularly the Department of Physics and Astronomy; the University of Bremen (UBREMEN); the University of Helsinki (UH), Fondazione Golinelli (FG) of Bologna, The Regional Directorate of Primary and Secondary Education of Crete (Greece), the Ellinogermaniki Agogi Sholi Panagea Savva (EA, Greece) and two associated partners: the Scientific Lyceum 'Albert Einstein' of Rimini (School, Italy), the Oberschule Findorff (School, Bremen).

The main goal of the project is to support teachers in teaching Climate Change through the following objectives:

1. Offer a comprehensive training framework for both in-service and pre-service teachers that will lead to their better understanding of Climate Change drivers and impacts and mitigation options and promote their efficiency in teaching and learning about Climate Change, equipping them with the necessary subject-matter knowledge and teaching strategies.

2. Build a teacher education European network and thus lead to an efficient methodology of teaching the next generation of European citizens.

As Loucks-Horsley and colleagues (2010) point out, traditional "mass" teacher professional development projects rarely succeed as they lack attention to each teacher's individual needs and opportunities for substantial teacher interaction and in-depth study and practice. For this reason, in the CLIMADEMY project, the approach to the pre-service and in–service teachers' training is based on the findings of research on teacher education showing that the teachers' learning and professional development are fostered when teachers are engaged in learning activities along with their colleagues within communities of practice (Akerson et al., 2009; Kyndt et al., 2016). In such a collaborative context, teachers who share a common goal discuss and reflect on their practice, gaining expertise through their interaction with peers. To maximise the inclusion of ongoing personalised support in such teacher training efforts, the project foresees the use of disseminators, namely trained teachers who aim to diffuse an innovation to a further number of teachers (Roesken-Winter et al., 2015). Initial communities of practice with the participation of in-service teachers and researchers will be formed within the participating countries aiming at developing educational material and models for Climate Change.

The project started in 2022 with a community that includes five co-designer teachers per country (national hub). Then, it will be open to other co-designer teachers in two further steps, as shown in the following figure:

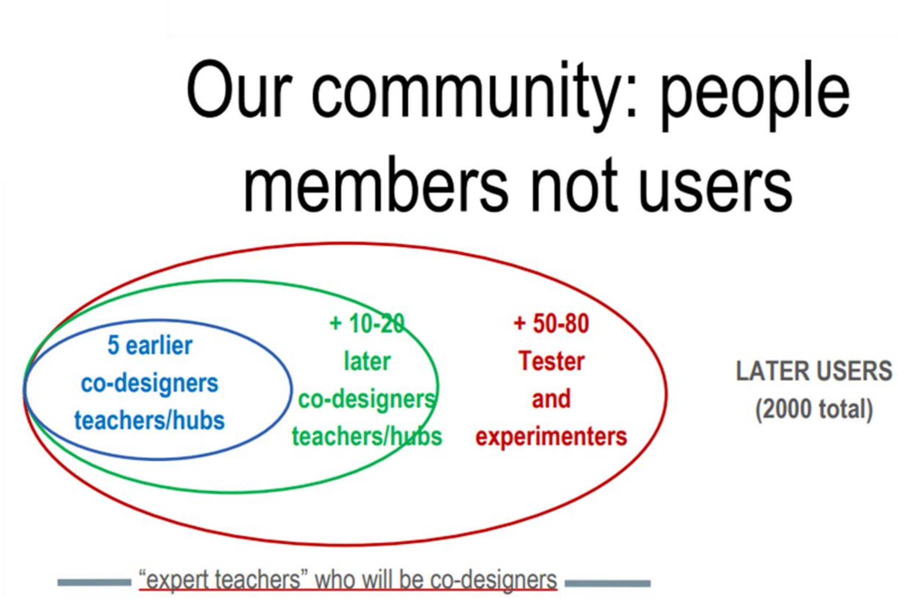


Figure 1. CLIMADEMY community

Each disseminator-teacher will undertake the dissemination of Climate Change to other colleagues, allowing a growing number of teachers to be addressed in the long term. Disseminator-teachers will act as informal mentors to their colleagues, and the interaction between them resembles mentorship.

The project is built around the following six Work Packages (WPs):

Work Package One: Project management, coordination and governance
Work Package Two: Educational materials on Climate Change
Work Package Three: Development of an educational model for teacher training
Work Package Four: Establishment of a common virtual Climate Auditorium (CLAUDI) and National Hubs
Work Package Five: Implementation of the Training Activities

Work Package Six: Impact assessment, dissemination and sustainability

The structure and links between WPs are illustrated in the figure below:

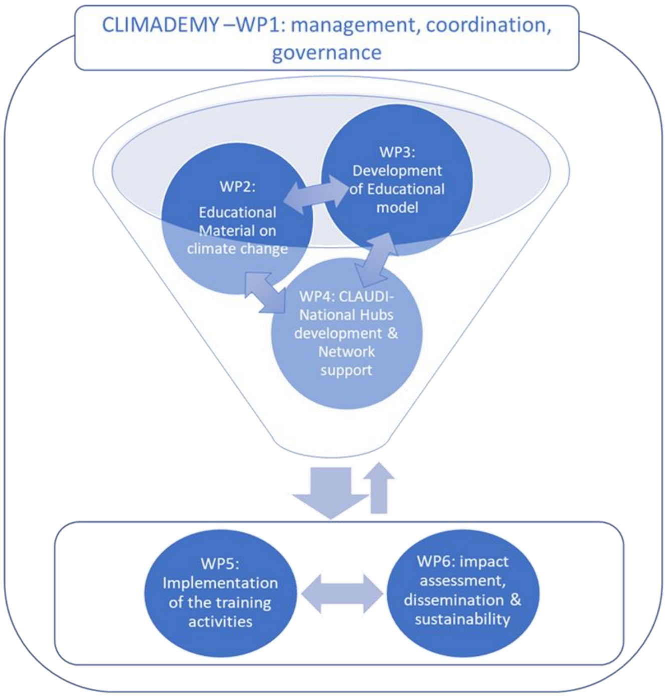


Figure 2. Structure of CLIMADEMY Work Packages

WP2 is in charge of educational material. Specifically, educational material focused on the drivers causing the human-induced climate perturbations, the impacts of Climate Change and the measures for sustainability is selected and/or designed. The materials are tailored for initial education and professional development and made openly available to all educational institutions across Europe. In-service and pre-service teachers have a key role in the selection, design and development of the material, acting both as trainees and co-designers. The materials and the teacher training activities are designed and implemented according to a pedagogical model developed in WP3.

Within WP4, one common virtual Climate Auditorium (CLAUDI) is at the basis of the Teachers' Academy networking and has the scope to connect four hubs, one in each country, with specific foci driven by regional particularities.

Two hubs have been established around two air pollution and Climate Change monitoring stations in two different regions of Europe that both experience exceptionally rapid Climate Change when compared to the global mean trends:

- The *Hyytiälä Forestry Field Station*[3], situated close to the Arctic region in a boreal forest in Finland
- The *Finokalia Atmospheric Observatory*[4], situated in the Mediterranean semi-arid subtropical region in Greece

One hub has been established focusing on computer modelling and space-based observations of the Earth system in Germany, namely the "Bremen hub".

Finally, a forty hub has been established focusing on the pedagogy of environmental education led by the University of Bologna and Fondazione Golinelli, namely the "*Italian hub*".

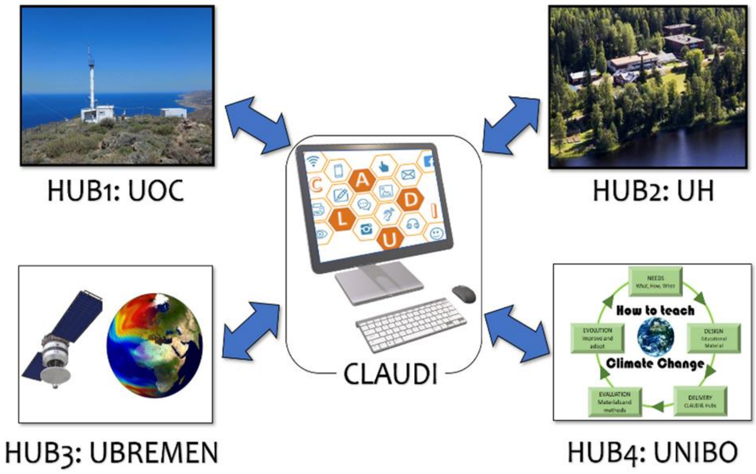


Figure 3. CLAUDI platform

The four hubs are linked to CLAUDI, a platform developed in WP4.

CLAUDI is the platform where all material produced in CLIMADEMY has been and will progressively be openly available, and online courses will be held. Furthermore, CLAUDI is the common place where teachers and learners can meet and exchange ideas or experiences about CC. The platform includes four Units in accordance with the national hubs (in the respective language) and the CLIMADEMY Auditorium, a virtual meeting place for the teachers (in English).

[3] https://www.helsinki.fi/en/research-stations/hyytiala-forestry-field-station

[4] https://finokalia.chemistry.uoc.gr/

In conclusion, the four hubs, through physical, virtual (supported by CLAUDI) and blended training, provide informal learning settings that can aid teachers in thinking differently about the practice of school science with respect to Climate Change.

This thesis work mainly contributed to WP3, coordinated by the Department of Physics and Astronomy "Augusto Righi" (DIFA) and led by Olivia Levrini.
WP3 works in close collaboration with WP2 so as to produce materials coherent with the "educational model for teacher education" that represent the main outcome of WP3. The educational model should include the following set of components:

a) guidelines to reconstruct scientific contents for educational purposes and to structure a model for teacher training;
b) criteria to outline learning goals in terms of knowledge, skills, abilities and competences;
c) pedagogical principles and pedagogical methodologies to be incorporated in the design of the activities and materials;
d) prototypes of activities implementing the pedagogical principles and methods;
e) assessment tools.

The tasks of the WP3 are the following:

Task One: Development of the educational model.
Task Two: Construction of a competence framework and assessment tools.

Several meetings with the CLIMADEMY partners have been scheduled to address these tasks and delineate a benchmark of the educational model.

My thesis objective was to contribute to co-designing and developing the pedagogical model. The specific objectives were the following:

- *Investigate teachers' needs and design strategies to address them in the pedagogical model;*
- *Carry out a literature study of the theoretical frameworks needed to build a pedagogical model for teacher education on CC;*
- *Point out the key messages of the pedagogical model;*
- *Develop a template to structure teacher education through the pedagogical model;*
- *Design or adapt prototype activities on CC to illustrate how to implement the pedagogical model in practice.*

The thesis work went beyond the specific tasks of the WP3, and I was guided in my study by the following research questions:

RQ1. "What are the pre-service and in-service teachers' needs about a teacher education on CC?"
RQ2. "What is the nature and depth of these needs?"
RQ3. "How can teachers' needs be considered by designing a pedagogical model for teacher education on CC?"

In the next paragraph, I try to address the first two research questions through a study of pre-service and in-service teachers' needs.

Chapter 2 - Study on pre-service and in-service needs for teaching Climate Change

2.1 Introduction

In this Chapter, I illustrate a study that I conducted about the teachers' needs in teaching Climate Change (CC). I used data collected from three different contexts. One context involved pre-service teachers and two contexts involved in-service teachers. The main goal of this study was to identify teachers' needs in teaching CC to compare them with the aspects of the pedagogical model that CLIMADEMY partners were developing in WP3.
The methodology used to analyse the data collected from the different contexts was the same. According to a bottom-up approach, a set of categories about teacher needs was built from the data. Then, the categories were converted into themes by triangulating the results with the research literature.
I started with the context of pre-service teachers, building the categories and converting them into themes. Afterwards, I changed the context and analysed data collected from in-service teachers. Firstly, the themes that emerged were discussed separately in paragraphs 2.3.1 and 2.3.2 for pre-service and in-service teachers respectively. Secondly, the comparison between pre-service and in-service teachers' needs was made, reporting similarities and differences (paragraph 2.3.3.). Thirdly, the results from the different contexts were integrated to obtain a final picture of the teachers' needs (paragraph 2.5).

Using the transcription of relevant discussions among teachers that I was able to collect in two peculiar situations (group three of the international workshop and the second part of the Italian workshop on class dynamics schemes) I studied the nature and depth of the teachers' needs. The result of this part was the identification of four main challenges in teaching CC that touch the professional identity of the teachers, a different vision of scientific literacy (SL), the nature of educational resources that are usually used in the classroom, and the culture and school organisation. The conclusion presented the final picture of the teachers' needs displayed in four different levels, the connected challenges of Climate Change Education (CCE) and prompted questions that need to be answered in order to meet the teachers' needs and challenges about CC emerging from this study.

2.2 The research contexts: data collection, goals and methods

This study on pre-service and in-service needs for teaching CC has been carried out to address the research questions RQ1 and RQ2. Data from three different contexts have been collected and analysed. In the following, I described such contexts of data collection, the goals and the methods of data analysis, and the results.

Context 1: Pre-service teachers activity (27th April, University of Bologna)

The first context regards pre-service teachers. It refers to a seminar during which I presented the state-of-art of my thesis to second-year Master's Degree Program students in the "Physics Education and History of Physics" curriculum at the University of Bologna (27th April 2023, UNIBO Laboratory of Physics Education). Most of these students aim to teach in Italian schools. They have followed different courses in Physics and Mathematics Education, and some have teaching experience in Italian schools. The number of participants was twenty, some online and some in presence.

After presenting the objectives of my thesis and before presenting my contribution to the draft pedagogical model, I invited the participants to use the sticky notes of a jamboard page to answer the following question:

- *"Which aspects should be faced, in your opinion, in teacher education on Climate Change?*

The answers were displayed on the shared screen randomly. During the discussion, I clustered the sticky notes to show emerging patterns and to stimulate the debate further. Then, I invited the participants to share their thoughts about their colleagues' answers and the dimensions/aspects that emerged. Finally, I presented the draft pedagogical model, making links with shared aspects in the previous activity.

The pre-service teacher answers were translated into English and reported in Table One for their analysis.

The pre-service teachers' answers were clustered according to a bottom-up approach. Then, the categories obtained were interpreted and discussed using the literature research findings. Aspects of the CLIMADMEY project and/or the pedagogical model were anticipated in some cases. Finally, I compared the themes about pre-service teacher needs with those I found from other contexts that involved in-service teachers (contexts two and three).

Context 2: Workshop with Italian co-designer teachers (8th May, Opificio Golinelli)

The second context regards in-service teachers. The University of Bologna and Fondazione Golinelli organised several workshops with the Italian co-designer teachers. This allowed me to collect in-service teachers' feedback.
In this study, I considered the workshop at Opificio Golinelli (Bologna) on the 8th of May 2023, organised by the Italian partners (Fondazione Golinelli & UNIBO). Six Italian co-designer teachers[5] and Italian CLIMADEMY partners participated in this workshop. Two activities were designed to engage the teachers with different purposes. Fondazione Golinelli members designed an activity to collect teachers' ideas about the topics of CC, teachers' and students' needs. The facilitator (CLIMADEMY partner of Fondazione Golinelli) prompted the teachers using the following questions:

- *What are the topics you attribute to CC? How can they be integrated into the curriculum?*
- *What do you need to teach CC?*
- *What do students need to learn about CC?*

[5] The Italian co-designer teachers are teachers of the following Italian schools: "Liceo Scientifico A. Einstein", "ITAER Baracca" (Forlì) and "ITAC Scarabelli-Ghini" (Imola). Some schools and teachers have already collaborated with UNIBO and FG in other European projects such as the ISEE project.

The co-designer teachers were divided into two groups, and these groups were invited to answer the first two questions. Researchers formed a third group, and the facilitator invited them to share about student's needs, focusing on the different nature of these needs.
In the end, one member of each group shared the answers with all participants, which were collected synthetically by the facilitator on a jamboard page.
In my study, I focused on the answers to question two about the teachers' needs (Appendix A.1.1).

Following a bottom-up approach I identified some categories of the in-service teachers' needs displayed in the data collected. Then, I tematised these categories, collocating the teachers' needs in the research literature.
To get a richer view of the in-service teachers' needs (paragraph 2.3.2), I integrated the result from the Italian workshop with the result from the data collected in a different context, namely the international workshop.

A second activity was designed by myself and the educational physics group of UNIBO. This activity was presented in Chapter Four and aimed to collect feedback about the draft pedagogical model. However, the schemes about class dynamics stimulated the teachers' discussion, opening a deeper understanding of teachers' needs and contributing to this study to address the RQ2 research questions. I used the transcription of this discussion (Appendix A.1.2) to reflect on the nature and depth of the teachers' needs that emerged from the discussion and to elaborate on how the needs could be positioned in literature and addressed in the pedagogical model.

Context 3: International workshop with co-designer teachers of the four CLIMADEMY hubs (9th May, Online)

The third context regards in-service teachers, too. An activity of community building (situated in the WP4) designed and led by Fondazione Golinelli members took place online on 9th May 2023. This activity involved the five co-designer teachers of each hub and was carried out with the help of the partners.
Specifically, the number of participants sorted by country is illustrated synthetically in the following tables:

Table 1. List of participants

	Italy	Greece	Finland	Germany	Tot
Co-designer Teachers	2	5	3	3	**13**
Partner Representatives	10	10	3	2	**24**
	12	**15**	**6**	**5**	**38**

A short presentation of the overall project and the hubs preceded the activity. Specifically, the activity was articulated in two parts. Three separate online rooms were formed in the first part, moderated by a project partner. The teachers are invited to present themselves and then share their expectations about the CLIMADEMY project. Precisely, the questions to prompt the discussion are the following:

- *Who are you? What do you teach?*
- *What are your expectations about Climate Change?*
- *How do you address Climate Change issues at schools?*

In the second part of the activity, the co-designer teachers and partners were distributed in four separate rooms, led by one partner of the project.

Guided questions were prepared by Fondazione Golinelli using two jamboard pages. Specifically, the first page involved the following question:

- *"Why do you think it is important to address Climate Change issues?"*
  (To answer from personal, teacher/professional and student perspectives)

The second page presented the following question:

- *"What do you think you need in order to develop effective activities on Climate Change? For example, in terms of tools, knowledge or other things."*

The co-designer teachers were invited to answer the questions, expressing their views and ideas to the group. The CLIMADEMY partner acted as a facilitator of discussion and collected the co-designer teachers’ answers on the jamboard pages. In the end, each facilitator presented the answers and the main points of discussion in the main meeting (plenary session).

I followed this activity and realised that the result of the second part of the activity (teachers' answers and discussion) could be used as a preliminary study of in-service teachers' needs for teaching CC. I used the outcomes of the second part to point out the in-service needs for teacher education. Precisely, teachers' needs, as reported by the facilitators, were first clustered according to a bottom-up approach and then integrated with those that emerged from the Italian workshop. Finally, I compared this picture of in-service teachers’ needs with those delivered by the pre-service teachers. The similarities and differences between pre-service and in-service teachers’ needs emerging from this study are discussed in paragraph 2.3.4 and enriched with the literature findings.
From the second part of this activity, I used the transcription of the group three teachers’ discussion to reflect on the nature and depth of the needs that emerged in the discussion and to elaborate on how the needs could be positioned in the literature and addressed in the pedagogical model. The deeper study allowed me to identify some key challenges in CCE (paragraph 2.4).

2.3 Teachers’ needs for teaching Climate Change - results from the analysis

2.3.1 Pre-service teachers’ needs

In the following, I present the pre-service teacher answers (Table 2). At the same time, the table shows the four categories that I used to cluster the answers and identify the pre-service teachers’ needs regarding teacher education on CC. Then, I re-elaborated in more detail these needs, expressing the link with the research literature and/or anticipating how these aspects are considered in the pedagogical model.

Table 2. Pre-service teachers' answers

Educational resources	Epistemological and conceptual issues	Social aspects and competencies	Interdisciplinarity
Designed activity, ready to implement in the classroom. It should provide explanations, related theories and possible laboratory activities to teachers	Importance of the math models	Understand the relationship between the individual, society and the environment	How to study the interdisciplinarity of the topic
Activities related to the national guidelines	Math and physics models used in studying CC	Foster the student agency	Build a path that acknowledges the value of interdisciplinarity
Curriculum activities and more general STEM activities	Use of simulations	CC as an important topic for future citizens	How to use the interdisciplinary that characterized the CC topic in schools
Laboratory activities such as the professor Tasquier G. activities on CC (activities experienced by the students during one of the master courses)	History of CC, possible causes, methods to recognize it, models and predictions	Future studies (reference to the professor Levrini Olivia's research)	
Laboratory activities to do in class	Reconceptualization of some scientific concepts. For instance, the radiation process	Deal with the fake news of CC	
		Learn to use a scientific approach to discard ideological views on CC	
		Treat in schools the adaptation and mitigation of CC	

The pre-service teacher needs can be thematised as follows:

N1. Teacher education should provide educational resources on CC

The first category includes five answers that share the need to provide educational resources to carry out activities for teaching CC. According to these answers, teacher education is required to provide well-designed resources to carry out activities on CC. The discussion that followed the collection of these answers displayed that the pre-service teachers perceive the lack of educational resources on CC as one of the major obstacles in teaching CC effectively. In the pedagogical model, the educational resources to carry out activity on CC are the result of an educational reconstruction process that 'transforms' content knowledge into content for instruction. In the CLIMADEMY project, new educational resources on CC will be developed, or existing resources will be adapted to teach CC according to the pedagogical model.

In addition, according to the pre-service teachers' answers, the educational resources should be resources to carry out curriculum activities and activities related to the national guidelines set by the Ministry of Education. Introducing environmental issues into the curriculum might have two important implications. It would offer students the opportunity to learn more about

socio-scientific topics and contribute to a more sustainable future (Dillon & Scott, 2002) as well as helping to engage and support them in learning more about science (Dillon, 2012; Svihla & Linn, 2011).
Finally, two students gave details about educational resources, such as providing resources to carry out laboratory activities. It opened the possibility of changing the traditional way of teaching since laboratory activities require different pedagogical methods. It is one of the relevant aspects of the pedagogical model I presented in this thesis dissertation.

The need for educational resources on CC did not surprise us; it was also found in in-service teachers' investigations.
However, an important question is:

"What kind of educational resources do pre-service teachers need in teaching CC?"

The following categories can help to answer this question since the pre-service pointed out which aspects should be considered in teaching CC.

N2. Teacher education should consider the epistemological and conceptual issues related to the disciplines

Some participants focused their attention on the discipline aspects. Their answers are related to the epistemological and conceptual issues of CC.
According to the research findings, the primary epistemological issues are related to the fact that climate science implies non-linear models whose features are very different from the classic and mechanistic views of modelling (Pasini, 2003). In addition, difficulties in coping with the models of the greenhouse effect are, for example, highlighted by Svihla and Linn (2012). Conceptual issues (e.g., radiation confused with heat) cause misunderstanding about the greenhouse effect and its connection with global warming. The epistemological and conceptual issues have been extensively explored in the literature. In Italy, relevant research has been done by Tasquier and colleagues (2016; 2017) and Besson and colleagues (2010). The students studied these aspects in their master's degree course, which can probably explain this set of answers. The epistemological and conceptual issues should be

incorporated into the design process of the activity. In the CLIMADEMY pedagogical model, it is part of the educational reconstruction process.
According to these group of answers, the educational materials to carry out activity on CC should treat issues related to the disciplines that imply a better understanding of the scientific content and scientific process. This request is aligned with Vision I of scientific literacy, which focuses mainly on learning about scientific content and processes for later application. However, the other categories in this study showed a more complex view of science education and scientific literacy depicted by the pre-service teachers.

N3. Teacher education should highlight the social relevance of the CC topic.

Other pre-service teachers focused their attention on aspects that were not strictly related to physics and mathematics. These answers highlighted the social relevance of CC.
The relevance of the social dimension is connected with a different vision of SL and science education. Vision I is connected with a transmissive vision of the educational process focused on the unilateral transmission of scientific knowledge and without a clear link to the social dimension of science, Vision II moves towards a socio-cultural and situated vision of the educational process, and finally, Vision III incorporated a transformative vision committed to participation and emancipation.
One pre-service teacher's answer is: "*CC is an important topic for future citizens*", expressing the tension between "preparing future scientists" and "science for all". However, the teachers' request for student agency, discarding the ideological views on CC and dealing with fake news on CC, suggests the more complex Vision III of SL, which focuses on problematised relevance for critical citizenship and sustainability, involving greater social engagement and citizen impact.

Treating *the relationship between individuals, the environment and society*, as asked by one teacher, is quite complex and leads to the topic of the individual role against the CC. In psychology, several studies demonstrate that shared responsibilities lead to a diminished sense of responsibility from a single individual (Weintrobe, 2012). Thus, the students should feel that their action is relevant and, at the same time, they should look for collaboration.

N4. Teacher education should face the interdisciplinarity nature of the CC topic

A set of answers was related to the interdisciplinarity nature of CC. Three pre-service teachers pointed out the interdisciplinarity nature of the Climate Change topic, asking how to study the interdisciplinarity of CC and deal with it in schools. Boon (2016) points to the conceptual difficulty of Climate Change science being of an interdisciplinarity nature as a cause of the general low knowledge levels of pre-service teachers.

It is worth noticing that the different visions of SL are also related to interdisciplinarity. Simonneaux and Simonneaux (2009) discussed different science-orientation of SSI education using continuums from 'cold' (emphasising monodisciplinary, scientific learning, and epistemic values) to 'hot' (also emphasising transdisciplinarity, political citizenship and philosophical values). At the 'cold end' [...] knowledge mobilised in the classroom is single-disciplinary science. At the 'hot end', it is discussed in interdisciplinary sessions in science and humanities".

The CLIMADEMY project involves teachers of different disciplines, not just science teachers. In this sense, the interdisciplinarity goes beyond the direct links between science-related disciplines (e.g. the chemistry and physics role in understanding the greenhouse effect), collocating the education of CC as a socio-scientific issue at the 'hot end' of Simonneaux's continuum.

The limitation of the list of needs presented above is related to the particularities of the sample since it is composed of pre-service teachers with a specific background in physics provided by the curriculum "History and Physics Education" of Physics Master Degree of UNIBO.

2.3.2 In-service teachers' needs

The first activity in the Italian workshop and the second activity in the international workshop were used to have a complete picture of in-service teachers' needs.

I used the summary of the group reports of the first activity in the Italian workshop and the teachers' answers, as reported by the facilitators in the international workshop, to identify the needs. Appendix A.1. reported this information. Instead, the teachers' answers collected from the international workshop were required to be fitted into categories in order to compare with the needs expressed by the Italian teachers. In the following, the clusters are shown:

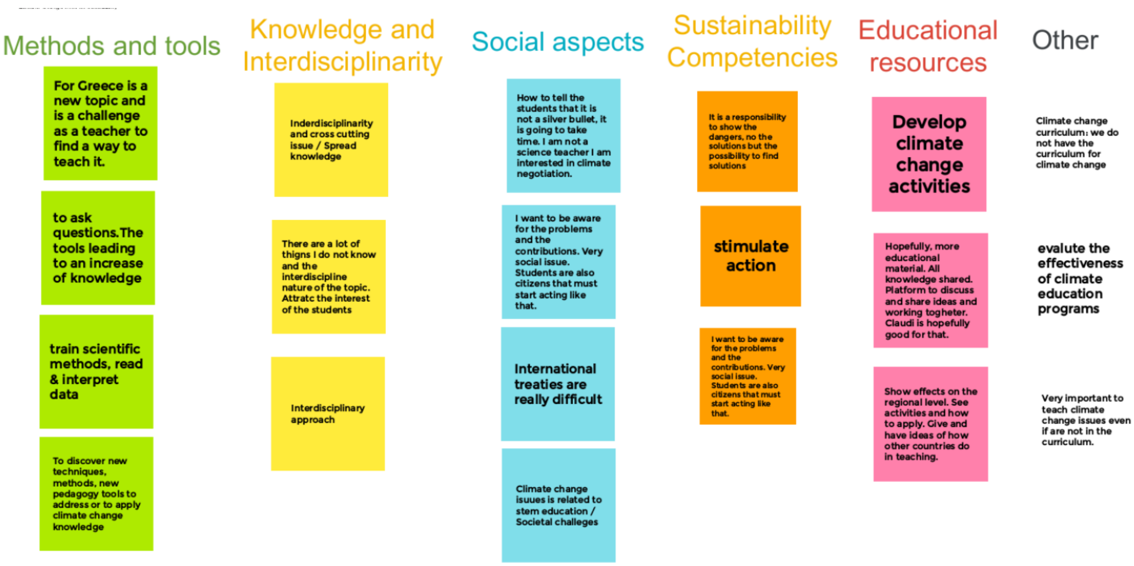


Figure 4. Clusters of teachers' needs

Integrating the results from the two activities mentioned above, the following set of in-service teachers' needs to address in teacher education on CC is provided.

N1. Teacher education on CC should provide knowledge

In the Italian workshop, group one underlined a problem related to the content to teach. According to this group, teachers do not have the information to teach CC. The lack of knowledge emerged in the international workshop as well.

However, Plutzer and Hannah (2018) showed that increased science coursework in college has modest effects on teachers' content knowledge and on their teaching choices. Contemporary education research on current scientific topics such as Climate Change highlights the importance of teachers' professional development both in terms of scientific content knowledge and of up-to-date educational methods to approach these topics (Blonder, 2010).

The teachers themselves expressed the need to equip teachers with new methods in order to teach CC, as shown by the following category.

N2. Teacher education on CC should equip teachers with new pedagogical methods.

In the Italian workshop, the need for new methods was expressed by both in-service teacher groups. However, group one argued the need for methods to treat coherently the multi-disciplinary competences. Group two claimed the need for methods in terms of interactions with students. Teachers' examples were Role-Game playing, debate and circle time teaching strategies. The latter need is related to the need for pedagogical methods to engage students, making them actively participate in CC issues.

According to Italian in-service teachers, teacher education should equip teachers with new educational methods to treat interdisciplinarity topics and to engage students. These requests are coherent with the CCE pedagogical strategies found in the literature.

In the systematic review of the CCE strategies conducted by Monroe et al. (2017), two themes were identified: (1) *focusing on personally relevant and meaningful information* and (2) *using active and engaging teaching methods*. Rousell & Cutter-Mackenzie-Knowles (2019) systematic review regarding Climate Change Education for children and young people identified *the need for participatory, interdisciplinarity, creative and affect-driven approaches to Climate Change Education*.

The teacher's need for new methods and tools in the international workshop also emerged. Specifically, they asked for new pedagogical methods and tools to teach Climate Change. One teacher underlined the need for new methods and tools to help students work with CC data. This teacher was probably thinking about the students' difficulties in using and interpreting complex system data.

N3. Teacher education on CC should train teachers using examples of activities or co-developing new activities

In the Italian workshop, group one argued that teacher education should not provide prepackaged activities ready to use in the classroom. Instead, teacher education should provide teachers with examples or prototypes of activities to have a structure that teachers can refill based on their needs. This structure should follow an educative model. It is worth noticing that this answer was given before the pedagogical model presentation (second part of the Italian workshop).

In the international workshops, the co-designer teacher shared the expectation to develop new educational resources to carry out activities on CC. This in-service teachers' expectation was probably related to their role as co-designer teachers in the CLIMADEMY project.

The need to provide examples of activities or design new activities could be related to a more 'practical view' of teacher education that foresees a way to reduce the gap between teaching and educational research.

The research-practice gap raises concerns regarding the utility of teacher education and education research more generally. The research-practice gap exists to a large extent because, beginning in their teacher preparation programs, teachers quickly find that recommendations from isolated research findings have little or no effect in their classrooms (Clough and colleagues, 2009). Pre-service teachers are commonly disappointed with their teacher education programmes (Korthagen, 2001; Wideen & Grimmett, 1995). They expect they will be told how to teach, and instead are presented with a myriad of teaching issues to consider that do not readily translate into how to conduct a lesson. Indeed, their perception that "theory" is largely irrelevant in learning to teach is one of the barriers that Russell (2002) considers to exist between student-teachers and their teacher education programmes (Loughran et al., 2008)

For these reasons, the key messages of the pedagogical model were extracted and an activity was designed to discuss and convey these messages in the CLIMADEMY hubs. The activity to be carried out in teacher education and designed according to the pedagogical model should convey not only new content knowledge but also new ways to position with respect to «teachers», content knowledge, sustainability competences and classroom dynamics. In this way, the teachers' disappointment can likely be avoided, and the barriers to learning to teach can be overcome in teacher education.

However, an important question is:

"Which kind of educational resources do in-service teachers need to teach CC?"

The following category helps to answer this question.

N4. Teacher education on CC should highlight disciplinary, interdisciplinary and social aspects

In the Italian workshop, group two argues that teacher education should equip teachers with knowledge about specific disciplinary topics, such as atmospheric stratigraphy and less known variables than carbon dioxide and topical issues such as nuclear power uses, electric cars diffusion and waste reuse. This request expressed the Vision I and Vision II of SL. Using the three types of knowledge identified by Aristotle, two kinds of knowledge are considered: Theoria/Episteme (Theoria as a way of thinking and arguing) and Techne (applying knowledge). The emphasis in science education is epistemological according to Vision I, while it is everyday life contexts and usefulness of science according to Vision II (Sjöström & Eilks, 2018).

However, in the international workshop, the social aspects emerged as key content to be treated in teacher education about CC. For instance, the interest in climate negotiation emerged. In addition, the awareness of students as citizens that has to take action is very strong among these teachers. This need for student action and political involvement is collocated in Vision III of SL, a praxis-oriented vision of SL. Using Aristotle's three types of knowledge, this request included the "Praxis/Phronesis", complementing Vision I and II with ethical and political values. According to this vision, the emphasis in science education is supplemented by ethics and transformation.

N5. Teacher education on CC should train teachers to guide and support students in the development of students' sustainability competences

In the international workshop, the in-service teachers expressed the responsibility and the desire to help students develop several competences (e.g., develop critical thinking). Consequently, the teachers' need that emerged from the study was to be trained to help students develop such competences. Precisely, they expressed students' needs that in the following picture were sorted according to the dimensions identified by group three (researchers) in the Italian workshop.

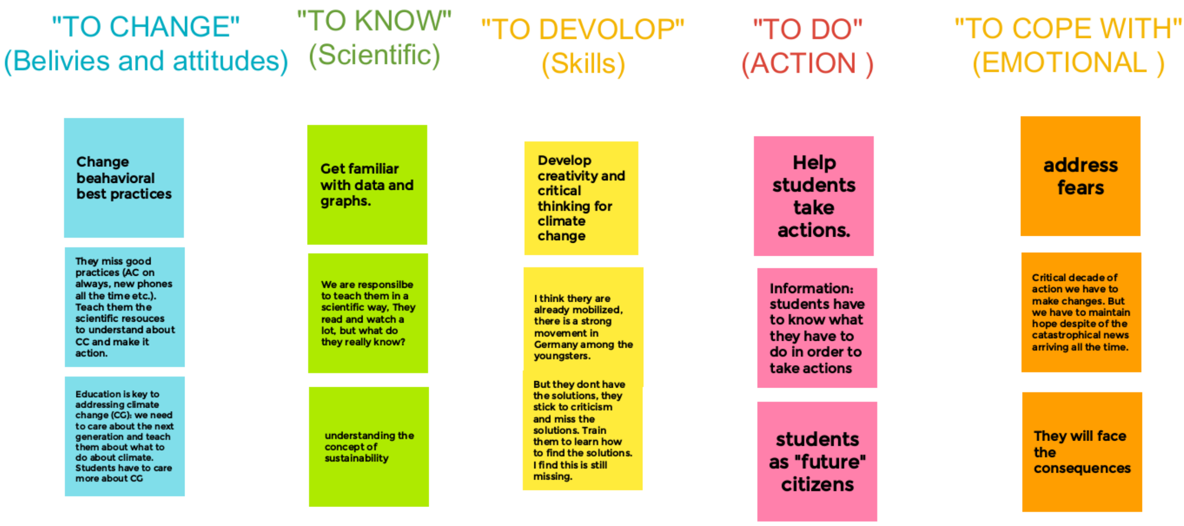


Figure 5: Clusters of students' needs

The use of a specific model that includes SSI competences in training may help teachers develop a stronger pedagogical base to support their teaching and learning about SSI (Nielsen et al., 2020). In the CLIMADEMY project, a competence framework for teacher education was developed starting from the GreenComp. The European sustainability competence framework (GreenComp) identifies a set of sustainability competences to feed into education programmes to help learners develop knowledge, skills and attitudes that promote ways to think, plan and act with empathy, responsibility, and care for our planet and for public health.

N6. Need for institutional support

In the international workshop, the in-service teachers underlined the institutional constraints limiting the possibility of carrying out activities on CC. The in-service teachers of group four answered the question about the need to develop new activities with new aspects that involved the school organisation (pink sticky notes from Figure 6). The latter group identified needs collocated at a different level with respect to the others, namely the level of school and culture organisation. This teachers' need is a demand for institutional support in order to have new spaces, more time, flexible curriculum and extracurricular activity in order to carry out activities on CC.

Figure 6. Group four answers to the following question: "What do you think you need in order to develop effective activities on Climate Change?" - The answers in pink describe some institutional constraints

2.3.3 Discussion - comparing in-service and pre-service teachers' needs

In the following discussion, the in-service and pre-service teachers' needs in teaching CC are compared and situated in the literature about CCE and SSI-teaching.

In our study, the need for knowledge about CC was explicitly expressed by the in-service teachers and not by the pre-service teachers. However, the pre-service teachers expressed the need to treat conceptual and epistemological issues about CC. I argued that this kind of request is also linked to the need for knowledge since it involves a specific knowledge domain, which in this thesis work was considered using the concept of pedagogical content knowledge (PCK). The PCK is seen as a unique domain of knowledge denoting the blending of content and pedagogy into an understanding of how particular topics, problems, or issues may be organised, represented, and adjusted to the diverse interests and abilities of learners (Shulman, 1987). Science education involves many disciplines and, consequently, different knowledge domains. Besides scientific knowledge, teachers should consider the history and philosophy of science issues and the complexity of the learning and teaching process (involving pedagogy and psychology knowledge). In our study, the in-service teachers expressed the need to deal with the complexity of the learning and teaching process, asking for new pedagogical methods to teach CC. The need for new methods to teach CC is a standard request among in-service teachers and not among pre-service teachers. However, about pre-service teachers, Garrido Espeja and Couso (2020) found that the most challenging aspect of teaching SSI activities was to include scientific information in a way that facilitated cogent argumentation among students. In addition, they had significant difficulties coordinating students' discussions. Therefore, I argue that both pre-service and in-service teachers need new methods to overcome the traditional and common 'image' of class dynamics, where a teacher has the knowledge and students «receive» it. Letting students discuss and make their own decisions on contentious societal issues is different from all variations of teacher-centred teaching (Nielsen et al., 2020). However, this does not mean that the latter is the norm in all classrooms. A traditional teaching approach is not the only possibility since different patterns can emerge during teacher-student interactions, as shown by Tabak and Baumgartner (2004). In the CLIMADEMY pedagogical model, we used the participant structure framework as a starting point to discuss class dynamics. Difficulties in coordinating students' discussions were also found for in-service teachers (e.g., Bryce and Gray, 2004). More generally, contemporary education research on current scientific topics such as Climate Change highlights the importance of teachers' professional development both in terms of scientific content knowledge and of up-to-date educational methods to approach these topics (Blonder, 2010).

Providing knowledge and new pedagogical methods are needed to teach CC. However, from a practical point of view, teachers asked for educational resources in order to carry out activities on CC. The need for new educational resources on CC emerged among both the pre-service and in-service teachers' answers. The difference between pre-service and in-service is related to the fact that in-service considers the possibility of designing a new activity or adapting a 'prepackaged' activity. Precisely, according to the pre-service teachers' view, teacher education should provide well-designed resources to carry out activities on CC. However, this view of providing 'prepackage' activities to teachers avoids considering the institutional constraints that affect the possibility of using education resources to implement a CC activity as was designed by others. The Italian co-designer teachers during the workshops highlighted the need to have examples of well-designed educational resources during teacher education. Consequently, at the same time, these resources should leave room for the teachers to adapt them to their classrooms' needs. The in-service teachers in the international workshops expressed the expectation of developing new activities, probably related to their role as co-designers in the CLIMADEMY project. I argue that the pre-service view of providing prepackage activities to teachers avoids considering the institutional constraints that affect the possibility of using education resources to implement a CC activity as was designed by others. In contrast, the in-service teachers were aware of the institutional constraints limiting the possibility of using some educational resources to carry out activities on CC. The in-service teachers' awareness of the institutional constraints is proved by the teachers' answers about their needs in carrying out activities on CC. In the international workshop, they highlighted some institutional constraints, specifically lack of time, lack of a flexible curriculum to include CC and lack of space outside the curriculum to treat CC. By definition, a condition becomes a constraint when it cannot be modified by the person in his/her position, at least not in the short run. For instance, the way of grouping students by age or the distribution of contents into subjects are constraints related to the positions of teachers and students, even if they can be modified from other positions, from educational authorities or politicians, for example. For this reason, the demand for a flexible curriculum, extracurricular activities, and more time to implement CC activities is collocated at a different level concerning the previous ones, that is the institutional level. These needs are grouped into a more general need for institutional support. To answer these requests, the school culture and organisation need to change.

More generally, regarding the implementation of SSI in teaching, Furman and colleagues (2020) found that long-term professional development programs for in-service teachers can benefit from developing competences in a stepwise fashion - starting with implementing teaching activities designed by others and progressing to increasingly co-develop the activities. For this reason, this research finding can combine the two pre-service and in-service teachers' perspectives about educational resources, starting with activities designed by others and going towards co-designed educational materials in order to deal with institutional constraints.

As for the important question about the kind of educational resources needed to teach CC effectively, pre-service and in-service teachers express the need to deal with specific disciplines' issues. This need was expressed differently among the three contexts of this study. The pre-service physics teachers underlined the need to know the physics conceptual and epistemological issues. In the Italian workshop with in-service teachers, the disciplinary aspects were considered in terms of knowledge to address topical issues or less-known disciplinary subjects. In the international workshop, one teacher underlined the need to teach scientifically and the need for methods to treat CC data. The disciplinarity aspect is undoubtedly essential. However, one risk is to reduce SSI to an instrument for teaching other parts of the curriculum, focusing on the disciplinary content knowledge. Leung and colleagues (2020) found that for pre-service teachers, the SSI is a vehicle for teaching content knowledge and the nature of science. That resonates with the finding about in-service teachers by Tidemand and Nielsen (2017) that SSI is often reduced to an instrument for teaching other parts of the curriculum - most notably content knowledge (Nielsen et al., 2020).

However, in our study, both pre-service and in-service asked for knowledge and methods that are needed to go beyond teaching discipline content knowledge.

Firstly, both pre-service and in-service teachers acknowledged the need to treat the interdisciplinary nature of CC. However, this need was expressed with general statements or general questions such as "*How to study the interdisciplinarity of the topic (CC)?*" that stated the problem in a general way. A step further in the issue of teaching interdisciplinary topics was done by in-service teachers. During the Italian workshops, teachers expressed the need for new methods and tools to coherently treat the interdisciplinary topic of CC. Finally, in the international workshop, the interdisciplinary nature of CC was considered to express the teacher's struggle in teaching an interdisciplinary topic. Using one teacher's words: *"It is a cross-curriculum topic: I have to incorporate chemistry, physics, and socio-scientific issues maybe. For me, as a teacher, it is challenging".*

Secondly, both pre-service and in-service teachers acknowledge the social relevance of CCE. The need to include the social dimension and aspects in teacher education on CC emerged often among the pre-service and in-service teachers' answers. However, the pre-service teachers expressed this point less precisely, for instance, including the expectations of treating the relationship between the environment, individuals and society. While the in-service teachers point out the social aspects more precisely, for instance, speaking about Climate Change as a socio-scientific issue (see the transcription reported in Appendix A.1.4).

The final need expressed by the teachers is related to the learning outcomes of CCE or, more general, SSI teaching, namely training students to develop several competences need to address CC. As the international science education community increasingly turn to the terminology of competences (e.g., Ropohl et al., 2018), the learning goals associated with SSI teaching are candidates for key competences that flesh out a Vision II or even Vision III of scientific literacy (Nielsen et al., 2020). From the teachers' answers and discussions collected in our study, differences were found for pre-service and in-service teachers. In-service teachers expressed the need to be trained to support and help students develop some sustainability competences, which had several links with the European sustainability competence framework (e.g., critical thinking). From the pre-service teachers' answers, this awareness about the sustainability competences did not emerge. Even if pre-service teachers acknowledged the social relevance of the CC topic, they did not set sustainability competences as a learning goal in teaching CC.

New pedagogical methods and a competence framework are needed to help teachers accomplish the learning goal of developing sustainability competences. However, what is missing from this teachers' needs investigation is the request for new assessment tools for SSI teaching. According to the research findings, science teachers avoid assessing students' competences related to SSI teaching, expecting that this is done in other disciplines (e.g., Steffen & Hößle, 2016), and they instead tend to focus on the science discipline content when assessing students (Christenson et al., 2017; Tidemand & Nielsen, 2017). In the CLIMADEMY pedagogical model, several assessment tools are included to help teachers in assessing sustainability competences.

2.4 Nature and depth of teachers' needs

The discussion with the co-designer teachers led to recognising teachers' needs. However, the debate was richer than the short answers that the facilitators or myself were able to collect. The nature and depth of the need were usually displayed in these discussions (e.g., lack of knowledge in teaching CC threatens the teachers' professional identity related to knowing everything about the topic). The themes that emerged from the groups were collocated in the literature. In the end, I anticipated how these themes could be considered using the pedagogical model.

I studied the discussion that emerged from group three in the second activity of the international workshop and the discussion that was stimulated by the second activity in the Italian workshop.

Precisely, Group Three was composed of a science teacher from Greece, a physics and maths teacher from Germany and a philosophy and ethics teacher from Finland. In addition to the facilitator partner, a guest partner of the project and I were present.
The transcription of the Group Three discussion is reported in Appendix A.1.4.
In the following table, I presented the answers as they were collected and summarised by the facilitator partner during the workshop. I excluded the answers related to the personal level relevance of the Climate Change issue from this study.

Table 3. Group Three answers, as reported by the CLIMADEMY partner

Participant	Teachers' needs	Students' need
German teacher	"It is our responsibility to show the dangers, not the solutions but the possibility to find solutions."	"I think they are already mobilized; there is a strong movement in Germany among the youngsters. But they don't have the solutions. Train them to learn how to find the solutions. I find this is still missing."
Greek teacher	"For Greece is a new topic, and it is a challenge as a teacher to find a way to teach it. There are a lot of things I do not know and the interdisciplinary nature of the topic. Attract the interest of the student."	"We are responsible for teaching them in a scientific way. They read and watch a lot, but what do they really know? They miss good practices (e.g. new phones all the time). Teach them the scientific resources to understand CC and take action. Change behavioural best practices."
Finnish teacher	"How to tell the students that it is not a silver bullet; it is going to take time. I am not a science teacher; I am interested in climate negotiation. International treaties are very difficult."	"Critical decade of action, we have to make changes. But we have to maintain hope despite the catastrophic news arriving all the time."

The discussion in the Italian workshops involved all six in-service teachers, the educational group of Bologna, partners of Fondazione Golinelli and myself. I referred to the discussion that in the second part of the workshop was stimulated by the facilitator about some schemes of class dynamics. In the Appendix A.1.2, the transcription of the discussion and the schemes are reported.

The main challenges of CCE that I identified through this study of the nature and depth of teachers' needs are thematised as follows:

C1. Changing teacher's professional identity as authority over the knowledge (Teachers accept the lack of knowledge about the topic)

According to the Greek teacher, CC is challenging because teachers do not have the knowledge to teach CC. The Greek teacher expressed this part as follows: "*There are a lot of things that I don't know. I haven't studied them*". Consequently, a teacher's need that emerged is the need to have more knowledge.

The need for knowledge has already emerged in our discussion in the Italian hub (8^{th} May, Opificio Golinelli). In that context, an Italian co-designer teacher pointed out the difficulties with answering the students' questions about such a complex problem as CC: "*When students ask something that I'm not familiar with (CC), I feel like:* '*Maybe I should know these things!*'". The Italian teacher perceived this inability to answer as their lack of knowledge. From these statements of the Italian co-designer teachers emerged a fear of having no answers for their students about CC. During the discussion, the group recognised that this fear is related to the self-perception of teachers as the possessor of all the knowledge about the topic. At the same time, the group conveys that addressing socio-scientific issues (SSI), such as Climate Change challenges, goes beyond one teacher's expertise and knowledge. One significant statement was: "*There is probably not an expert in Climate Change*". At the end of the discussion, the group was aware that in teaching Climate Change, the teachers should change the common self-perception over the knowledge. However, the teachers recognise that changing self-perception is very challenging.

The way to thematise this point had been the introduction of the "professional identity" of the teachers. The reason is that positioning differently concerning knowledge threatens the professional identity of the teachers as the possessor of all knowledge.

From these discussions with the co-designer teacher in the Italian and international workshops emerged that the pedagogical model considered new ways to position different concerning knowledge. This requires re-thinking the relation with respect to the knowledge.

The educational group of Bologna argued that this should be done in terms of sources of knowledge and classroom interactions (see the schemes presented in paragraph 3.4.2). In the next chapter, this point was extended with a discussion of the pedagogical model that can support teachers in positioning themselves differently regarding the topic of CC.

C2. Address a wicked problem by envisioning new possibilities through creativity skills (Teachers accept the current lack of solutions)

The other point is that the teachers, as well as their students, feel they do not have any solution for CC. The German teacher underlined that the German youths were taking action against CC. They are mobilising and protesting against the politicians. The risk for them is to be stuck in criticism. According to this teacher, the students do not have the solutions. In addition, the Finnish teacher highlighted that there is no "silver bullet" to CC, i.e., a short and magic solution to this complex problem. Acting against CC will take time.

Thus, the student's need for Climate Change is to be trained and guided in finding solutions.

Related to finding solutions, these teachers recognised that humanity will take time to deal with Climate Change, and today we do not have any solutions. In addition, the youngest are stuck in criticism and miss good practices. However, from the discussions emerged a sense of acceptance of the lack of solutions from the German and Finnish teachers. Even if we do not have the solutions today, we should maintain hope among the youngest. Using the German teacher's words: *"I think young people have enough energy, potential, and maybe even ideas to make it (climate) turn back fast. I think they can do it faster than we think".* Moreover, the teacher has a relevant role in making this scenario realised, as displayed in the following words of the same teacher: *"We can train them and give input as teachers to look for solutions."*

The way to thematise this point has been the introduction and discussion of CC as a "wicked problem", as it is presented in the GreenComp (Bianchi et al., 2022).

Specific competences are required to address a wicked problem. These reflections are relevant and guide us to another component of the competences in teaching Climate Change. Besides the scientific inquiry and action competences, some specific creativity competences to let students be able to find solutions are needed. Training the students to find solutions means developing specific competences. The pedagogical model considers this with a rich competence framework, where one important area is the "creativity competences". According to the Green Comp sustainability competences, this includes the competences of envisioning sustainable futures.

C3. Train the next generation to address SSI issues through sustainability competences and a critical approach (Teachers guide students in developing sustainability competences)

From the discussion of co-designer teachers (group three) emerged that the students' needs form their perspective can be summarised as follows:

- *Change their practices and behaviour;*
- *Be taught scientifically;*
- *Be trained to find a solution;*
- *Take action.*

From the discussion, it emerged that teachers feel responsible for satisfying these students' needs, even if some of these do not directly involve their discipline. This is evident in the Greek teacher's words, who is a science teacher. The teacher highlighted that their role is to teach the students scientifically: *"How can they find information (about CC)?"* and *"How can they read it?"*. However, this teacher feels responsible also for changing their practices and making them take action. Precisely, this teacher said: *"My role is to alter the way they think and the way they are acting"*.

The way to thematise this is related to the ability to deal with a "socio-scientific issue".

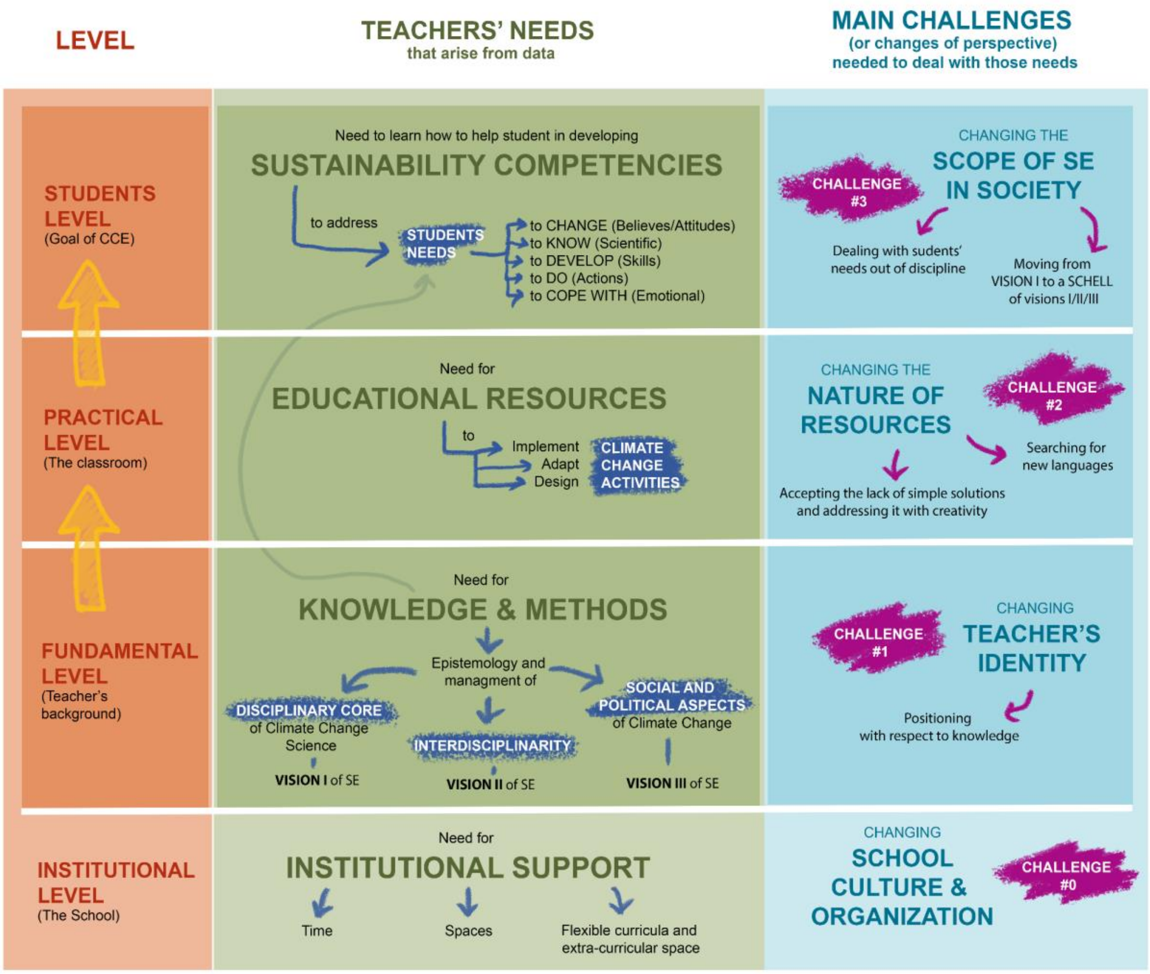
Socioscientific (SSI) issues are ill-structured problems that involve moral, ethical, and financial aspects and lack clear-cut solutions (Lee & Grace, 2012; Topcu et al., 2010), are usually topics that emerge from the nexus of science and society (Sadler & Zeidler, 2005), and have a degree of uncertainty. The ability to deal with socioscientific issues has been recognised as an important goal of science education (Zeidler, 2014), and by engaging learners with SSI, we can potentially help them understand the relevance of science to their lives (Stuckey et al., 2013), understand aspects of the nature of science and how people use it, and develop their capacity to be critical consumers of scientific information (Kolstø, 2001; Levinson, 2006).

Introducing SSI in science teaching can also be supported by Roberts' (2013) Vision II of science, which aims to promote the understanding of the usefulness of scientific knowledge by using meaningful content. By including socioscientific issues in science learning and teaching, we could move science classes towards unwrapping and engaging discussions about the intersections of science and society, promote scientific practices, and potentially invite students to act responsibly and participate actively. This "knowing in action" (Aikenhead, 2006) aspect of SSI is related to what Sjöström and Eilks (2018) define as Vision III scientific literacy – one that includes socio-political action and moral-philosophical perspectives.

Finally, a complex version of socio-scientific issues (SSI) based on science education (e.g., Bencze et al., 2012) has similarities with Bildung-oriented science education. Bildung is a complex concept. Schneider (2012) describes Bildung as a reflexive event and its function is to form the self in a complex meaning-making process that covers the whole range from early childhood to the advanced age. Bildung-oriented science education aims at making the student capable of a self-determined life in his/her socio-cultural environment, for participation in a democratic society, and for empathy and solidarity with others (e.g., Elmose & Roth 2005). In other words, it implies a politicised science education aiming at emancipation and socio-ecojustice (Sjöström & Eilks, 2018)

2.5 Conclusion

To summarise the teachers' needs, I propose the following scheme in which the teachers' needs are collocated at four different levels.



Figure[6] 7. The overall picture of teachers' needs in teaching CC

At the fundamental level, I collocated the teachers' needs that involve their own background as teachers and professionals. In order to teach CC, knowledge and methods are needed to deal with the disciplinary core, the interdisciplinarity nature of CC and finally, the social and political aspects. This type of need represents a challenge for both the teachers and the teacher trainers since it shows that teaching CC touches the professional identity of the teachers as the possessor of all knowledge.

[6] This figure was built by myself and Emma D'Orto.

Other teachers' needs are collocated at a more practical level, namely the need for educational resources needed to carry out activities on CC in the classroom. In this study, I illustrated that pre-service teachers ask for educational resources ready to implement, while the in-service teachers consider the need to adapt or design new educational resources according to their classroom's needs. In addition, this type of need represents a challenge for both the teachers and the teacher trainers since it requires to reflect on and change the nature of educational resources in order to deal with the lack of current solutions to restore our climate and the lack of ready-made educational packages. Creativity and new languages, as well as wide room for adopting and adapting the resources to different contexts and in a fast-changing society, should be part of the attitude of teachers approaching CC resources.

The teachers need to know how to train and guide students in developing sustainability competences to face CC. This is the goal of CCE and is collocated at a new level - student level. Developing sustainability competences represents a challenge for both teachers and teacher educators since it implies to regenerate the vision of SL and science education itself. Competences out of the disciplines are required, and Vision I of SL should be integrated with Vision II and Vision III of SL.

Finally, the discussion about the in-service and pre-service teachers' needs enriched our study by introducing a new level. Some needs in teaching CC are out of the teachers' reach. It involves the school culture and organisation. Teachers complain that they need institutional support to teach CC. Since CC touches in depth space-time and disciplinary structure of school, it also represents a challenge for the school culture and organisation. Schools should be regenerated and reconceptualized as ecosystems with different stakeholders and inner dynamics that share processes for establishing the vision and the priorities of the institution.

This study about teachers' needs was conducted in parallel with the development of a draft pedagogical model based mainly on the literature findings and researchers' experience (Chapter 3). The literature study and teacher investigation study let me point out how the teachers' needs can be situated in educational research, and vice-versa, understand which framework can be used in the pedagogical model in order to respond to such teachers' needs.

This transition from the teacher needs to the pedagogical model was a response to the general ambition of this thesis to find a fertile intersection between the teachers'' needs and the educational research findings.

In the following, I reported guide questions to identify the theoretical frameworks in the literature that can help in addressing some teachers' needs that emerged from the study presented in this chapter.

The need for knowledge and methods can be met by providing a teacher education course. To do that, relevant questions to answer are the following:

- *How teacher education activities on CC should be structured?*
- *Which kinds of methods should trainer teachers use during teacher education?*

Teacher education should train teachers in implementing, adapting or designing educational resources in order to meet the teachers' need for educational resources to carry out activities on CC. Therefore, the pedagogical model should be able to answer the following question:

- *How can we train teachers to design or adapt educational resources to carry out activities on CC?*

These resources should address the disciplinary issues and incorporate different disciplines and social aspects. Implementing, adapting or designing educational resources of this kind is a challenging request for teachers. Relevant questions are presented in the following:

- *How can we adequately 'transform' scientific content into content for instruction?*
- *What is the educational value of this content for instruction?*

However, the teachers need to accept the lack of knowledge about CC. For these reasons, new methods to implement activity on CC should be considered. Specifically, the new methods influence the role of the teacher, supporting different class dynamics. Guide questions are the following:

- *How do we deal with the complexity of class dynamics?*
- *What is the source of knowledge? How are these sources linked?*

A rich competences framework is considered in the pedagogical model in order to respond to the student's needs. In addition, teachers are supposed to have a key role in helping and guiding students in developing such competences. Therefore, the model will be developed also to deal with questions like:

- *What are the sustainability competences?*
- *How can these competences be developed in schools?*
- *How can these competences be assessed?*

Suitable competences and innovative structure participants can foster the acceptance of the lack of solutions.

The pedagogical model will provide answers to these questions. The theoretical frameworks of the pedagogical model are presented in the next Chapter. The model required some adaptation to be presented in the hubs. I contributed to pointing out the key messages of the model and thinking about how they could be conveyed in the Italian hub. The result was a co-designed activity for the teachers in the hub (co-designer teachers) that is illustrated in Chapter Three (paragraph 3.8). The model also led to the design of a template to be used to discuss, present or analyse training activities on CC. In order to show how the template could work, I used it to illustrate how the pedagogical model can be implemented in the description of educational resources. Specifically, the first application is about the biodiesel activity designed by Giulia Tasquier and Eleonora Barelli from the University of Bologna. The second application is about an activity that I designed in which students work with the data provided by the IPCC Atlas platform.

Chapter 3 - CLIMADEMY Pedagogical Model

3.1 Introduction

The activities carried out within CLIMADEMY in the different hubs will have a "pedagogical identity". The pedagogical model provides this pedagogical identity to the activities. This model was built by the researchers involved in WP3 and myself. Specifically, the WP3 has engaged the University of Bologna, the University of Helsinki, the University of Crete and Fondazione Golinelli.
The WP3 is articulated in the following two tasks that have been performed together and in a strict collaboration between the partners:

Task One: Development of the educational model.
Task Two: Construction of a competence framework and assessment tool.

These two tasks have been achieved through a collaborative process among the partners. We carried out a series of workshops, during which we shared research frameworks, examples of teacher training activities and examples of analysis of such activities. The partners shared and benchmarked educational frameworks in the first two online meetings (23rd November 2022; 27th January 2023). These meetings allowed the group to pave the way to draft an educational model for CLIMADEMY. In addition, in the second meeting (27th January 2023), the partners presented and analysed examples of training activities. After that, they built a draft of the Pedagogical Model for teacher training in the following meetings (7th March 2023; 29th March 2023).

My contribution to this model started with a literature analysis of the theoretical frameworks. Then, I focus on specific issues in the first draft of the pedagogical model. Specifically, the role of the MER and how to describe the student-teacher interactions using two different models.

The developed model helps to figure out how to position the teachers concerning the content knowledge, competences, teacher education activities and classroom dynamics.
One issue that this work thesis helped to address was adapting the pedagogical model for the co-designer teachers in the hubs. It required reducing the technical language and extracting the key messages of the pedagogical model. This issue is located within a more general problem related to the research-practice gap regarding educational research. Recommendations from isolated research findings often neglect the complexities in learning and teaching, and therefore, when implemented in classrooms, they often fall well short of the advertised effect. (Clough et al., 2008). The University of Bologna educational group presented the pedagogical model to the Italian co-designer teacher in a workshop (8th May, Opificio Golinelli), activating the general discussion about the model and asking for feedback.

In this Chapter, I presented the frameworks through which we built our pedagogical model. For each framework, I explained its features and its linked research. Then, I discussed our view about the key messages of each framework. For key messages, we intend the messages that we would like to convey to the teachers during teacher education. Each part was enriched with the feedback of the Italian co-designer teacher where available.

3.2 The Model of Educational Reconstruction

The CLIMADEMY project aims to provide the teachers with guidelines to reconstruct the scientific content for educational purposes since the co-designer teacher will design new materials on CC or re-elaborate existing material. CLIMADEMY adopts the model of educational reconstruction (MER) as the main reference for this purpose. It has been designed and refined by German scholars.

3.2.1 The MER and its three components

The term *reconstruction* denotes that some issues that got lost in the process of formation of scientific knowledge have to be reconstructed to make the scientific point of view understandable and meaningful to learners. Because educational issues unavoidably influence the analysis of content structure, the authors of the model use the term *educational* *reconstruction*. The model of educational reconstruction assumes that three components are intimately connected (Duit et al., 2012).

These components are the following:

1. *The clarification and analysis of science subject matte*r.

This component includes the clarification and analysis of the key science concepts, principles, science processes, and views of the nature of science, as well as the significance of science in various out-of-school contexts. This component aims to clarify the specific scientific conceptions and the content structure from an educational point of view. Two closely linked processes are included: clarification of subject matter and analysis of educational significance. Clarification of subject matter draws on qualitative content analysis of leading textbooks and key publications on the topic under inspection but also may take account of its historical development. Science terms that might be misleading to learners, especially words of different meanings in science and everyday life, should also be considered. Research methods for subject matter clarification are analytical in nature, and content and text analysis methods prevail. History and philosophy of science issues are also taken into account. Analysis of educational significance is also analytical in nature, drawing on pedagogical norms and goals. Empirical studies on the educational significance are included, e.g. by employing questionnaires to investigate the views of experts.

2. *The research on student and teacher perspectives*

This component includes the research on student and teacher perspectives regarding the chosen subject (including pre-instructional conceptions and affective variables like interest, self-concepts, attitudes and skills). The process of clarification and analysis of science content, on the one hand, and the process of content construction for instruction, on the other, need to be based on empirical research on teaching and learning. Some empirical research concerns the students' perspectives, investigating their pre-instructional conceptions and affective variables like interests, self-concepts, and attitudes. In general, many studies on teaching and learning processes and the particular role of instructional methods, experiments and other instructional tools should be considered. Furthermore, research on teachers' views and beliefs of science concepts, students' learning difficulties and their role in initiating and supporting learning processes are essential. The research literature on teaching and learning science is extensive. A wide spectrum of methods is employed, ranging from qualitative to quantitative nature, including questionnaires, interviews and learning process studies in natural settings.

3. *The design and evaluation of learning environments (e.g. instructional materials, learning activities, teaching and learning sequences).*
This component comprises the design of instructional materials, learning activities, and teaching and learning sequences. Key resources of the design activities are research findings on students' perspectives (e.g., their potentialities, learning difficulties as well their interests, self-concepts and attitudes) on the hand and the (preliminary) results of subject matter clarification on the other. Both resources are regarded as equally important for designing instruction.

3.2.2 The key messages of the Educational Reconstruction

As we claimed before, we do not expect that teachers will strictly use this model. However, we invited the teachers to use this model as a tool for reasoning in designing activities. For this reason, we focus on some crucial points of the model to share with co-designer teachers in the following. An essential point of the MED is the interconnection of the three components. They are strongly interrelated and influence each other mutually, as shown in the following figure.

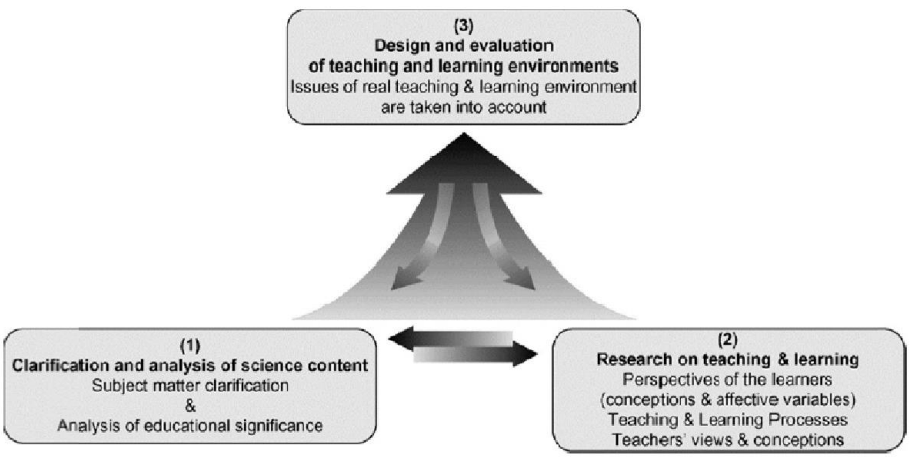


Figure 8. The three components of the Model of Educational Reconstruction (Duit et al., 2012)

The first message concerns two kinds of knowledge: scientific knowledge and students' learning difficulties knowledge. These two kinds of knowledge belong to the two different components of the MER, which should be integrated and balanced in designing a learning environment. We can formulate this message as follows:

(Key message 1) In planning instruction, the science content to be learned and students' cognitive and affective variables linked to learning the content should be given equal attention.

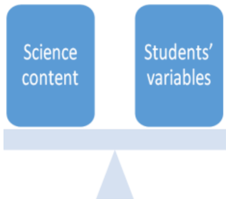


Figure 9. First key message - the balance between two kinds of knowledge

This message clarifies the main aim of the model, namely designing appropriate learning environments that consider both the analysis of the scientific content and the students' perspectives. However, the procedure is not linear because the interaction between the first two components does not lead directly to the final third component. Nevertheless, the procedure is recursive when the teachers reconstruct a content structure for instruction. The following figure shows an example of a complex interaction between the components to get instruction modules.

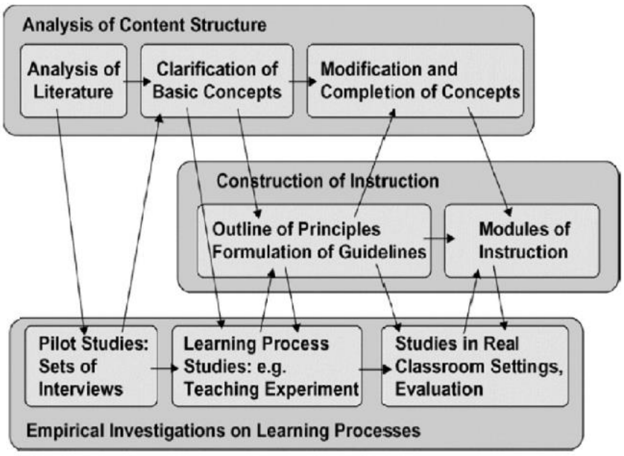


Figure 10. An example of the recursive process of Educational Reconstruction (Duit et al., 2012)

The second message that we extracted from the model of educational reconstruction can be directly formulated using the model authors' words as follows:

(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).

This message is important for us because we try to overcome traditional thoughts about the content structure for instruction. Many teachers and some science educators think that the content structure for instruction should be "simpler" than the science content in order to meet students' understanding. Accordingly, they call the process of designing the content structure for instruction *reduction*. However, this view misses the point. In a way, the content structure for instruction should be much more complex than the science content structure to meet the learners' needs. It is, therefore, necessary to embed abstract science knowledge into various contexts to address the learners' learning potentialities and difficulties.

Specifically, the MER provide two steps (Figure 11) to follow in designing the content structure for instruction:

(1) ‘Elementarization’
(2) Construction of content structure for instruction (Education potential & Enrichment)

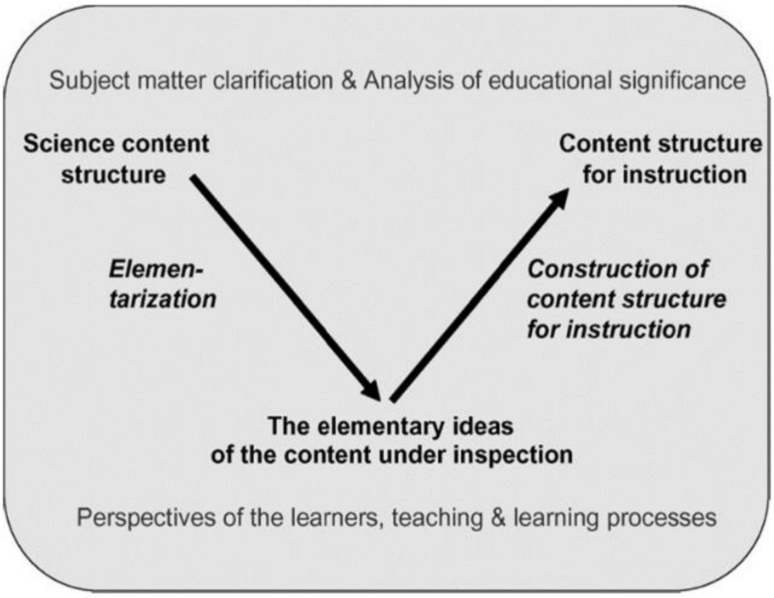


Figure 11. Steps towards the content for instruction (Duit et al., 2012)

The ‘elementarization’ leads to the elementary ideas of the content under inspection. ‘Elementarization’ criteria are the following: (i) Scientific agreement; (ii) Students’ variables (prior knowledge, ideas and interests.); (iii) Targeted competences.

We notice that the interconnection between the components is very deep in the model since, in the ‘elementarization’ process, we also have to consider the students’ variables (second component) with the science content (first component). An elementary concept or idea of science content needs to be put into contexts that make sense to the students and can be understood by them. In this sense, the teachers enrich the science content, which becomes richer from an educational point of view.

These two messages are also related to some important characteristics of the design of learning environments:

(i) Science education as an interdisciplinary scholarly discipline

The following figure shows several disciplines connected to science education.

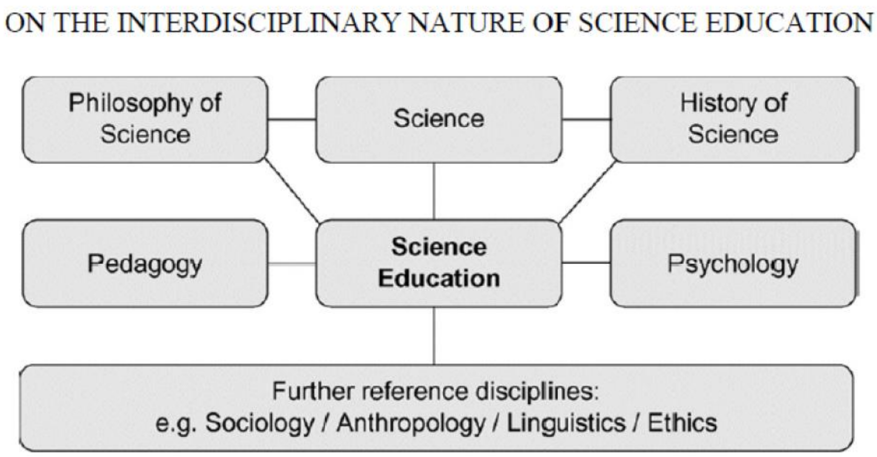


Figure 12. Reference disciplines for Science Education (Duit et al., 2012)

As we claimed before, teachers should consider two kinds of knowledge in designing a learning environment. The last scheme highlights the complexity related to the design of a learning environment since it shows how many disciplines are employed in the science education field. Starting from the analysis of the science content, the teacher or researcher should understand the science, also considering the history and philosophy of science issues (this can guide the 'elementarization' process, for instance). The teacher or researcher should then consider the learning and teaching process involving pedagogy and psychology. Nevertheless, this is not all since they should consider the social relevance and help students sense-making, asking ourselves, "why a scientific topic is essential to be taught?". Therefore, they should analyse the social relevance and help students in sense-making. Consequently, other disciplines can be involved in this analysis. There is no doubt that science education is an interdisciplinary discipline, and professionals in this field should have different kinds of knowledge and skills. These skills and knowledge are one aim of teacher education. In this context, the MER model is specifically used to foster the teacher's professional development (detail was presented in the 2.3.3 section)

(ii) The teacher's knowledge of the scientific content is not enough to teach the content

If we want to characterise the domain of knowledge about a topic to teach it, we can introduce a new concept, namely Pedagogical Content Knowledge (PCK). This peculiar knowledge domain can be defined as follows:

"Pedagogical Content Knowledge is seen as a unique knowledge domain denoting the blending of content and pedagogy into an understanding of how particular topics, problems, or issues may be organised, represented, and adjusted to the diverse interests and abilities of learners" (Shulman, 1987)

In the following figure, an example of the PCK specified for teaching CC is illustrated.

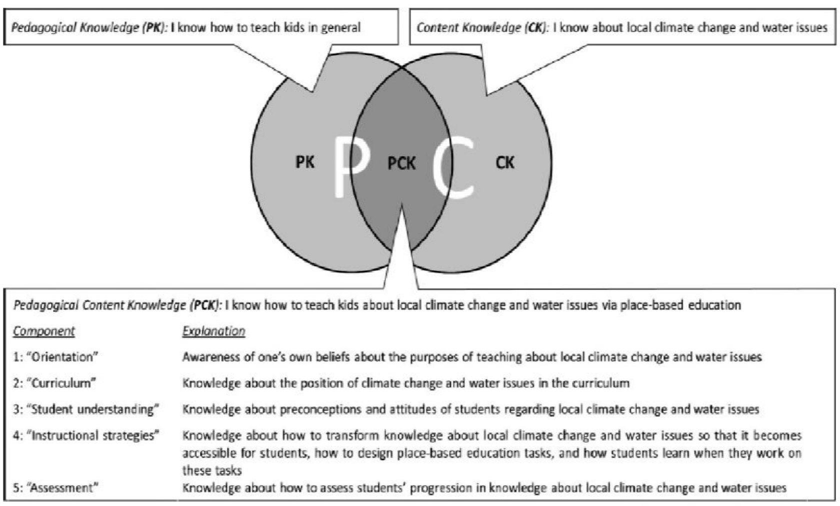


Figure 13. Shulman's PCK framework, specified for teaching about Climate Change and water issues via place-based education (Favier et al., 2021)

If it can be obvious that knowing how to teach is not a sufficient condition to teach CC without knowing the science content. It is less evident that knowing about CC is necessary but insufficient to teach CC. In addition, even if teachers knew about the students' difficulties and the science content, they could not know how to overcome them. Thus, in terms of Pedagogical Content Knowledge, the CLIMADEMY project aim is to equip the teacher with a particular domain of knowledge to teach CC.

The model of educational reconstruction lets us think about the complexity of the teaching and learning process and opens several dimensions. However, the MER model is still insufficient to cover all the aspects. We introduced other frameworks during our meeting within WP3 to discuss teacher education activities, class dynamics and sustainability competences. Before that, the role of MER in CLIMADEMY teacher education is specified in the next paragraph.

3.2.3 The Role of MER in Teacher Education

One issue during the pedagogical model's development was understanding the MER's specific role. The model can be used to structure teacher education or foster the teachers' professional development (during the workshops with the co-designer teachers and during teacher education, respectively). The Model of Educational Reconstruction provides a theoretical framework and guiding principles for educational design in science education, both at the research and school levels. For this reason, it can be employed for different purposes.

In the first place, the MER was developed as a model for instructional planning - in school practice and curriculum development groups. In the following picture, the scheme of the educational reconstruction process for this initial purpose is reported.

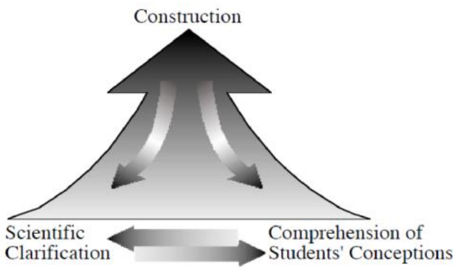


Figure 14. Components of the Model of Educational Reconstruction (Kattmann et al., 1996)

However, it has been developed and can be used for other purposes:

- Science Education Research;
- Teacher Professional Development;
- Teacher Education.

Specifically, we are interested in the MER as a model for further Teacher Professional Development and designing guidelines for science teachers' education.

Duit, Komorek and Muller (2004) distinguish three key domains of teacher thinking in planning and analysing instruction:

(A) Constructivist views of teaching and learning

Teachers are aware that students interpret everything presented to them from their private perspectives. They also take into account that knowledge may not be simply passed to students but that their role is to sustainably support students in constructing their knowledge themselves. Further, teachers should embed science topics in contexts that make sense to students.

(B) The fundamental interplay of instructional variables

Teachers should be aware of the interplay of the variables composing instruction, namely Aims & Objectives, Content, Methods and Media, i.e., take into account that, for instance, the choice of a particular method is also a choice for emphasising certain aims.

(C) Thinking in terms of the process of educational reconstruction

The content structure for instruction has to be adjusted to student pre-instructional conceptions and needs to be embedded into contexts that make sense for students.

Thus, the MER can contribute to these key domains of teacher thinking and foster the Teachers' Professional Development.

The 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 can 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, considering empirical research on teachers' views on teaching and learning, their needs and their knowledge.

In the ERTE model, the following research domains are integrated:

(1) *Clarification of concepts of Educational Structuring*

This component comprises the major ideas of the MER.

(2) *Empirical research on teacher education*

This component includes investigating teachers' views (specifically their PCK). It is essential to critically clarify and analyse the conceptions of teacher education in the literature.

(3) *Guidelines for teacher education*

Finally, the last component is about the guidelines for designing efficient settings for teacher education. As the educational reconstruction process, the process to obtain guidelines is recursive. The aforementioned components are strongly interrelated, and they influence each other mutually.

In the following figure, the ERTE model and its components are illustrated.

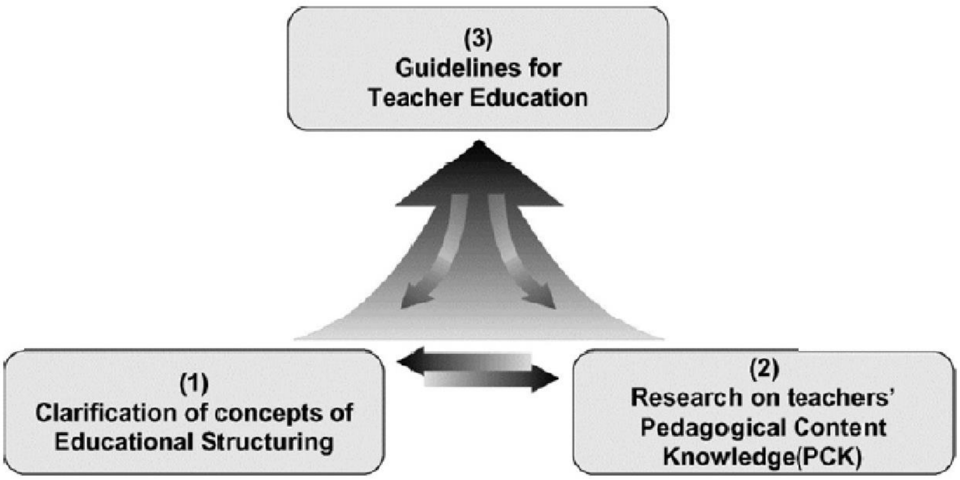


Figure 15. Educational Reconstruction for Teacher Education (ERTE)

In conclusion, we decided that the MER in the CLIMADEMY project will play two different roles related to the two different phases of the project.
In the first phases, we aim to develop efficient settings for teacher education with the co-designer teachers. For this aim, the MER can provide guidelines in which the aspects above are taken into account. However, in the second phase, in which in-service teachers will be trained, the add-value of using this model is to foster Professional Development.

3.3 Teacher Education Activities

I presented in this paragraph the "Study and Research Paths for Teacher Education" model that has been chosen to address the following questions:

- "What activities will teachers do in Teacher Education?"
- "What learning outcomes are we planning to achieve through the teacher training activities?".

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

The SRPs-TE model was developed by Barquero & Bosch (2015) within the paradigm established by the anthropological theory of the didactic (ATD) for mathematics education (Chevallard, 1992). The "Study and Research Paths for Teacher Education" aims to integrate mathematical modelling into current educational systems. In particular, the main goal of this model is to study the institutional constraints and how new teaching proposals can overcome these. The strategy of the SRPs-TE is asking the teacher participants to assume different roles during the educational process. This role-play appeared to be a successful strategy for making different institutional constraints emerge. A condition becomes a constraint when it cannot be modified by the person in his/her position, at least not in the short run. For instance, the way of grouping students by age or the distribution of contents into subjects are constraints related to the positions of teachers and students, even if they can be modified from other positions, from educational authorities or politicians, for example. The main difficulty in approaching the institutional constraints is their "naturalisation", the fact that we take them for granted as part of the nature of our environment. It is thus difficult even to notice them from inside the institution. Thus, the activities following the SRPs-TE model help to make important constraints visible to teachers. Dorier and Garcia (2013) underline that teachers and students are part of a complex system with its dynamics, conditions and rules, affecting and shaping their actions. It is thus essential that teacher education, as a complement to the individual approach, also embraces an institutional approach to focus on the conditions, resources, strategies and settings offered by the different institutions that intervene to make teaching possible and suitable. Thus, the researchers are perfectly aware of the fact that many of the evidenced institutional constraints are out of the teachers' reach and, thus, cannot be faced only through teacher educational proposals. A more global approach involving the whole educational system and not only its main actors is needed. This aspect will be a more general limitation of the CLIMADEMY project since not all the institutional constraints can be faced through innovative teacher education proposals or the adaptation of well-designed educational resources to carry out activities on CC.

3.3.2 The four types of activities for Teacher Education

For CLIMADEMY, the SRPs-TE model is chosen to articulate the learning outcome in terms of the role and position that the activity requires the teacher mentees to assume. The adaptation of the structure of the SRPs-TE model consists of four types of activities (Figure 16). Each of them asks teachers (indicated as participants in the following) to assume different roles. In the following, we present the description of these roles, adapted for the CLIMADEMY purpose:

Type 1 Participants are asked to address initial questions, share their knowledge and play the role of "*explorers*". This type of activity aims to break the ice and to have a first look at what exists and what emerges from and around them. Participants' ideas and knowledge play a relevant role in this phase.

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 content or activities that could, to a certain extent, be also reproduced and used in an ordinary secondary classroom. Assuming this role, teachers become more aware of the students' difficulties by "putting themselves in their shoes" for a while.

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 their role and adopt the role of "analyst". Participants are asked to analyse their previously developed activity on different levels or layers to appropriate them. At this stage, educators introduce some tools/instruments to progress collectively with participants on the analysis of the materials.

Type 4 consists of sharing some secondary school experiences with participants (or, if there is a chance, designed and implemented by themselves). 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". During the adaptation, teachers are expected to «reduce» the potential of the instructional activity to face their school's institutional constraints.

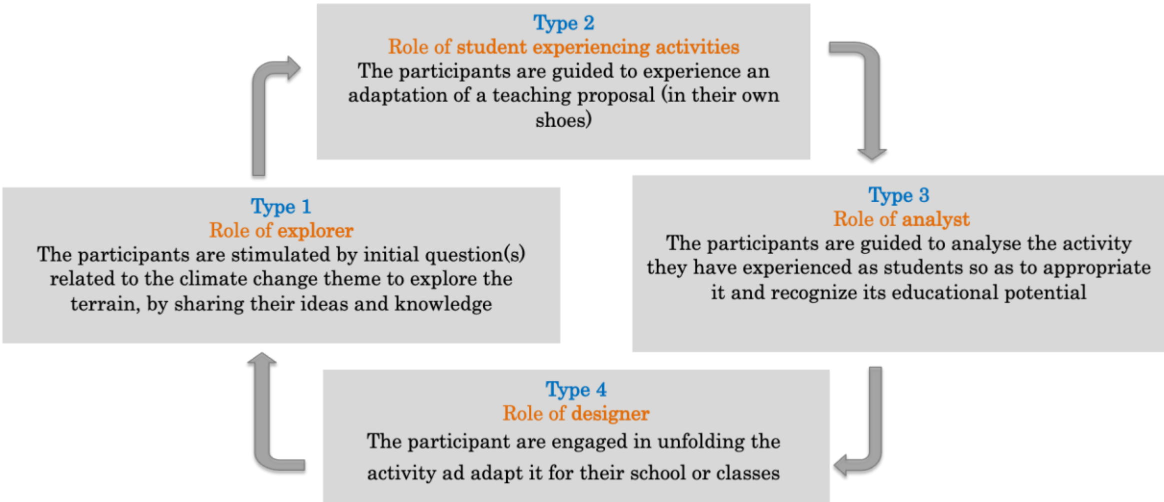


Figure 16. Adaptation in submodules' structure of the SRP-TE (Adaptation from Barquero et al., 2008)

The first co-designer teachers' impression of this model was that it is a step-by-step model. This model can help teachers feel confident during their teacher education, and more importantly, it does not require them to play the role of expert. The role of the expert has been discussed a lot in our workshops with the Italian co-designer teachers. The reason is that the teachers do not know enough about this topic. During one of the first workshops with the Italian co-designer teachers, one teacher presented the presence of an expert on Climate Change during teacher education as an essential point. This request suggests the need to acquire knowledge about the topic.

According to the SRP-TE model, teachers learn about CC, particularly in the role of student, and this should be one step of the entire process when teachers design or adapt activities for instruction. During teacher education, some experts on a specific topic can be invited. However, educators and mentors in teacher education cannot have passive teachers. In contrast, the teachers should be activated in this role to appropriate the content. For this reason, the presence of an expert is not a complete solution to the lack of knowledge. Finally, we noticed that this model is used for two different but linked situations. When we design the activities for teacher education, the co-designers have to consider which kind of role the student and in-service teachers are invited to assume. In addition, during teacher education, through this model, the teacher mentees should know which roles are invited to play.

3.4 Classroom dynamics

When teachers design educational resources to carry out an activity on CC, they should consider the pedagogical methods to enact these activities in the classroom. The CLIMADEMY project aims to help teachers use new methods through which they position themselves differently concerning the classroom to foster students' understanding and engagement. During the WP3 meeting with researchers, we started to discuss the result of the research in Science Education, with a particular focus on the participant frameworks. Then, we focused on their adaptation to teacher education on CC.

3.4.1 The Participant Structure Framework

The participant structure framework is presented to discuss the possible teacher-student interactions. A participant framework shows the setup of the class scenario 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, when can they speak, and what can they say?" (Hegedus & Penuel, 2008)

Examples of Participant frameworks taken from Tabak and Baumgartner (2004) and freely elaborated (Levrini et al., 2019) are the following:

- "Teacher as a monitor"

This participant structure is characterized by an asymmetrical relationship, an Initiate-Respond discourse pattern, sometimes followed by Feedback (I-R-[F]), and the nature of instruction is explicit: The teacher is the repository of the knowledge, she/he asks about procedures, tasks and completion of task-related milestones.

- "Teacher as a mentor"
  An asymmetrical relationship and an I-R-F pattern still characterise this participant structure. Instruction is also explicit, but unlike in the monitor framework, I-R-F leaves "room for interpretation, negotiation, and adaptation of ideas, rather than the testing and evaluation (E) found in typical recitation I-R-E patterns". In this participant structure, "the teacher tries to help the students to align their thinking and actions with scientific norms without dictating actions or explanations" (Tabak & Baumgartner, 2004).

- "Teacher as a partner"
  This participant framework is similar to the teacher as a mentor framework. However, 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 the teacher as a partner framework, the teacher is no longer the sole authority, and multiple students are authorised to speak; knowledge is distributed and can be generated by the single participants or as a result of classroom interaction.

Tabak and Baumgartner (2004) focus on these three participant frameworks. Their research focuses on analysing the "teacher as partner" participant framework to support inquiry-based science education. However, these three participant frameworks are not exhaustive. Other participant frameworks defined in the following are possible:

- "Teacher as perspective-maker" (co-teaching contexts)
  This participant structure can emerge in co-teaching contexts, where each teacher plays a role of an expert on one possible view. Knowledge is distributed among the teachers and the students, and it can be generated by single participants or as a result of classroom interaction.

- “Teacher as moderator of the discussion”

  This structure can emerge when 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 as a result of classroom interaction.

The “teacher as perspective-maker” particularly fits teaching Climate Change since it is an interdisciplinary topic and different expertise is required. The feeling of being unable to answer the students and the lack of competences could be overcome if the teachers of other disciplines enact this kind of participant structure.

Furthermore, the participant framework can provide criteria to characterise the dynamics of teaching/learning within a class.
In the previous description of participant structures, the criteria used to characterise a participant framework are:

- Accountability, which refers to who has the knowledge and how the knowledge is distributed in the class, that is, “who can speak what and when?”
- Knowledge distribution, which can be “asymmetrical or symmetrical in teacher-student relationships” (active–reactive);
- Discourse pattern (directive as an IRE pattern or indirective as a facilitated discussion)

For the pedagogical model, we use the participant framework to describe the type of interaction within the class and the different roles and responsibilities that teachers and students can have in teaching Climate Change. These aspects are relevant because the teachers during teacher education can change how they position themself with respect to the students.
However, when we consider the participant framework and evaluate the educational potential of one structure, we should consider the following limitations:

1. *Interactions between students and teachers have a history*

What affects the degree of trust and reciprocity in interactions are not just the content and structure of dialogue in here and now but the residual and accruing effects of all past interactions that these participants share (Stone, 1993).

2. *Participant structure can emerge as the teacher's in-action response*

Even if the "teacher as partner" participant structure has pedagogical potential, rendering the how and the why of cultural tools visible. However, the partner structure seems to emerge as the teacher's in-action response to the students' struggles rather than a calculated consideration of issues of symmetry (authoritative and internally persuasive discourse in balance), as in the Tabak and Baumgartner analysis (2004) emerges: "They (the students) were struggling and just needed to have her (the teacher) sit and work through part of the investigation with them".

For these reasons, teachers will develop the sensibility to change their way of teaching considering the student's needs and during the evolution of time if the teachers are trained about other possibilities in positioning themselves with respect to the students. We have previously identified some criteria to characterise the class dynamics. However, these criteria are still too complicated to use for reasoning about the complex class dynamics in teacher education on CC. For this reason, in the next paragraph, I presented some evocative schemes that the Physics Educational group of Bologna University (led by Olivia Levrini) used with the co-designer teachers to activate a discussion about class dynamics in the Italian hub.

3.4.2 The main messages for the classroom dynamics

Tabak & Baumgartner's results and characterisation are highly demanding for teacher education on Climate Change. The Italian partners started to discuss this part with the co-designer teacher in the Italian hub through very simplified schemes to get some interesting points to present during teacher education (see paragraph 3.9).

The main messages that we aim to convey for the classroom interactions are the following:

Key message 1: *The traditional and common 'image' of class dynamics, where a teacher has the knowledge and students «receive» it, is not the only possible since different patterns can emerge during teacher-student interactions*

A teacher's voice does not necessarily have to be univocal by virtue of his or her institutional authority. Teacher-student dialogues can reflect varying degrees of dialogicality (Tabak and Baumgartner). The distribution of knowledge can be symmetric or asymmetric according to the different participant structures. However, it is reductive to assume that the sense of symmetry can be attributed solely to partner interactions. For instance, more symmetry can be achieved by changing the discourse pattern (feedback, revoicing).

Key message 2: *Reach a balance between the authoritative and persuasive discourse*

Tabak and Baumgartner's work points out that the tension between what Bakhtin calls "authoritative discourse" and "internally persuasive discourse" triggers the mastering of cultural tools and the appropriation process. The authoritative discourse is a discourse that must be taken in without negotiation. The internally persuasive discourse is one that becomes one's own only through interaction with one's own words.
A balance between these discourses is needed because if science, through its instructions, is perceived as strictly authoritative, then students will shy away from personal meaning-making. In contrast, if there is no measure of authoritative perspectives, then normative ways of knowing, doing and talking will not come across as sources from which students should draw on in an interanimating relation in crafting their own words (Tabak and Baumgartner)

3.5 Mentoring Relationship

3.5.1 Educative Mentoring and the MERID Model

Educative mentoring is perceived as 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 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 the 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 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, and summarising).

MERID is a two-dimensional model which incorporates two aspects of mentoring dialogues: the mentor’s style (degree of directiveness) and their initiative of introducing topics for conversation (degree of input).

According to the MERID model, the aforementioned dimensions, the degree of the mentor’s directiveness and the degree of initiation of topics for discussion define four distinct mentoring roles in the context of mentoring conversations.

- 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;

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

The four mentoring roles can be represented as in the following figure:

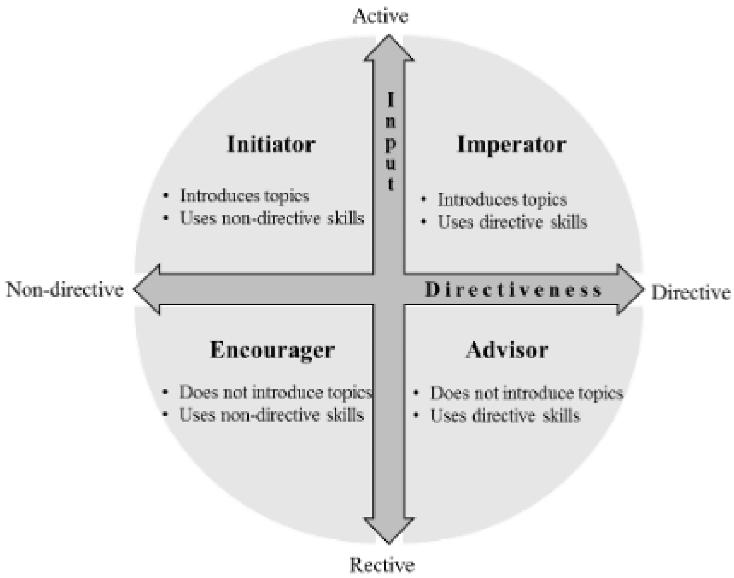


Figure 17. The MERID model (Michailidi & Stavrou, 2021)

Mentors participate in mentoring conversations with different roles, shifting their mentoring style in the course of mentoring meetings and among the discussed topics.

3.5.2 The main messages - from teacher education to the classroom

The first consideration is that we cannot expect teachers to interact with their students differently from the traditional recitation lesson if we use the same methods in teacher education. In this sense, the way in which the mentors interact with teachers during teacher education should be suitable with how we expect teachers to interact with students in their classrooms after teacher education. For this reason, the main messages of the MERID can be transferred from teacher education to classroom interaction.

Key message: Mentors/ Teachers participate in the mentoring/classroom conversations with different roles, shifting their mentoring/teaching style in the course of mentoring *meetings/lessons and among the discussed topics. Specifically, as mentees/students gain experience, mentors/teachers shift their mentoring/teaching style towards non-directive skills (e.g. from lesson modellers to encouragers).*

The research of Michailidi and Stavrou (2021) showed that:

- As mentees gain experience, mentors shift their mentoring style towards non-directive skills (e.g. from lesson modellers 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.

- The imperative role is mainly adapted when discussing the modules' objectives and scientific content, topics on which mentees lacked fundamental knowledge (asymmetric knowledge distribution). Instead, when the discussion revolved around issues on which mentees have extensive experiences, such as general pedagogical issues and their students' cognitive and affective background, mentors gave them room to express their views.

In CLIMADEMY, the researchers and mentors should not support the superiority of any one role over the others in terms of their effectiveness in supporting the mentees/students. On the contrary, they should emphasise the value of providing adaptive mentoring which fits the needs and learning style of the mentees/students. The degree to which mentors/teachers can adapt and meet the ever-evolving needs of mentees/students is an essential factor in the effectiveness of the learning process.

3.6 Sustainability Competence Frameworks

3.6.1 GreenComp framework

In WP3, we started our discussion about the competences referring to the GreenComp.
European sustainability competences have been recently described in the GreenComp framework (Bianchi et al., 2022), developed as part of the European competence framework

development. GreenComp aims to foster a sustainability mindset by helping users develop the knowledge, skills and attitudes to think, plan, act with empathy, responsibility, and care for our planet. GreenComp is the result of a robust research methodology that has involved a large and diverse group of experts and stakeholders to build a consensus on an agreed proposal. It is designed to support education and training programmes for lifelong learning. It is written for all learners, irrespective of their age and their education level and in any learning setting - formal, non-formal and informal.

GreenComp has adopted the following statement to define a sustainability competence:

"A sustainability competence empowers learners to embody sustainability values and embrace complex systems in order to take or request action that restores and maintains ecosystem health and enhances justice, generating visions for sustainable futures" (Bianchi et al., 2022)

In the GreenComp framework, four main areas of sustainability competence have been identified: 1) Embodying sustainability values, 2) Embracing complexity in sustainability, 3) Envisioning sustainable futures, and 4) Acting for sustainability. Each of these areas has three competences named, as shown in the following table.

Table 4. Sustainability competences according to the GreenComp framework

Competence Area	Competences
1. Embodying sustainability Values	1.1 Valuing sustainability 1.2 Supporting fairness 1.3 Promoting nature
2. Embracing complexity in Sustainability	2.1 Systems thinking 2.2 Critical thinking 2.3 Problem framing
3. Envisioning sustainable Futures	3.1 Futures literacy 3.2 Adaptability 3.3 Exploratory thinking
4. Acting for sustainability	4.1 Political agency 4.2 Collective 4.3 Individual initiative

3.6.2 CLIMADEMY competence framework

Our goal for teacher education is to apply the GreenComp competences to the context of Climate Change teaching in schools and try to make concrete wordings that help teachers to identify concrete learning outcomes, give examples of activities on how they can be trained in schools, and how to assess them. Therefore, the CLIMADEMY competences framework is richer for the teachers than the GreenComp and helps them in choosing, designing or adapting activities on CC in developing certain sustainability competences in the youth.

The Finland researcher partners have recently worked in a ClimComp[7] research project (https://blogs.helsinki.fi/climatecompetencies/about/), where competences needed for Climate Change mitigation and adaptation have been studied both among youth and climate experts of the society. The Finland-researched findings (ClimComp, Taurinen et al., under review; Siponen et al., under review) have been applied to the GreenComp model to form a CLIMADEMY framework, utilisable by teachers in school environments.

The CLIMADEMY climate change competence framework is illustrated in Figure 18.

Figure 18. CLIMADEMY competence framework - Climate Change competences for schools

The structure of the previous figure highlighted the following:

Values and attitudes are seen as the foundation of Climate Change competence of the youth; *Scientific inquiry* is a group of basic competences in the framework; *Creativity* and related abilities to design new solutions are much needed in order to build sustainable futures; *Action* competence brings competence to real life and is built on top of all of that.

[7] ClimComp project blog (2021-2024): https://blogs.helsinki.fi/climatecompetencies/

From the content of each CLIMADEMY competence, the Finland researchers drafted the learning outcomes, the pedagogical methods and the assessment tools - based on the literature review and their experience in teaching Climate Change.

The outcome was the following four tables.

Table 5. Values and attitudes related competences

1 VALUES AND ATTITUDES

Competencies	Learning outcomes	Activities in schools	Assessment
1.1 Valuing sustainability **1.2 Supporting fairness** **1.3 Promoting nature** **1.4 Well-being** **1.5 Justice and collaboration**	• Excitement (motivation) • Get interested in CC • Value and care for nature, sustainability, others, and oneself • To identify unsustainable practices and willingness to change them	• Transformative learning • Role playing • Reflection, dialogue, discussion • Reading fiction, storytelling • Projects and concrete doing right from the beginning i.e. videos, visits	• Portfolio assessment • Learning diary • Concept-mapping • Evaluation of artifacts i.e., report, exhibition, video • Formative and diagnostic assessment

Table 6. Scientific inquiry competences

2 SCIENTIFIC INQUIRY

Competencies	Learning outcomes	Activities in schools	Assessment
2.1 Systems thinking **2.2 Critical thinking** **2.3 Problem framing** **2.4 CC science orientation**	• Knows the scientific basis of CC • CC impacts and interactions • Mitigation and adaptation • Critical scientific thinking • Big picture, linking theory to action • Use of CC knowledge and willingness to use this knowledge in: 1. Explaining climate phenomena scientifically (argue) 2. Identifying/recognizing climate issues and climate related questions or problems 3. Drawing evidence-based conclusions, i.e., interpret news, information, data and evidence scientifically	• Project based learning, inquiry i.e. searching information, writing, analysing data, evaluating arguments • Independent study • Collaborative and co-operative learning • Learning in small groups, explaining to others, discussing with others	• Tests and examinations • Portfolio assessment • Learning diary • Concept-mapping • Evaluation of artifacts i.e., report, exhibition, video • Formative and diagnostic assessment

Table 7. Creativity competences

3 CREATIVITY

Competencies	Learning outcomes	Activities in schools	Assessment
3.1 Futures literacy **3.2 Adaptability** **3.3 Exploratory thinking** **3.4 Leadership**	• Use of CC knowledge • Willingness to use this knowledge in: 1. Identifying or recognizing climate related challenges 2. Designing and evaluating solutions i.e., new ways to act to prevent CC 3. Problem solving; new ways of thinking i.e. alternative futures; thinking big	• Creative and collaborative design, design thinking • Art-based methods • Problem solving • Envisioning	• Portfolio assessment • Learning diary • Concept-mapping • Evaluation of artifacts i.e., report, exhibition, video • Formative and diagnostic assessment

Table 8. Action competences

4 ACTION

Competencies	Learning outcomes	Activities in schools	Assessment
4.1 Political agency 4.2 Collective action 4.3 Individual initiative 4.4 Implementation 4.5 Justice & Collaboration 4.6 Well-being	• To plan and conduct concrete actions and evaluate them • To know decision-making structures • To identify own potential and limits and to take care of own well-being • To communicate and co-operate with others	• Project-based learning • Collaborative and co-operative learning • Collaboration with society, project management, group leadership • Hands-on doing, concrete outcomes	• Portfolio assessment • Learning diary • Concept mapping • Evaluation of artifacts, i.e., report, exhibition, video • Formative and diagnostic assessment

These tables are used as a starting point in designing activities with the co-designer teachers in each hub. This means that the co-designer can enrich and adapt these tables. After this phase, these tables or their re-elaboration can be used as a reference in teacher education.

In the next paragraph, the assessment tools for sustainability competences are presented.

3.7 Assessment tools

The summative assessment is traditionally considered relevant in Italian schools. However, when we treat social-scientific issues in schools, we should ask ourselves if the teachers should assess the students on this topic. This point was discussed with the Italian co-designer teachers when they presented their activities on CC (4th April 2023, Opificio Golinelli). I asked them if the presented activities were supposed to be assessed. I received two different answers:

- The activity of the Rimini Einstein school did not foresee an assessment. The teacher sustained that the assessment is not very meaningful because this activity is supposed to be performed in the extra school time and involves different disciplines.
- The activity of the Baracca School provided an assessment, and this activity was supposed to be performed during school hours.

These teachers' answers suggest that curriculum activities should be assessed while extracurricular activities should not. However, the teacher was probably thinking about a summative assessment with the main goal of giving a grade on the student's learning. However, different kinds of assessments are possible and valuable. In particular, diagnostic assessment (assessment before learning) and formative assessment (assessment during learning) can play a role both in curriculum or extracurricular activities.

Within the CLIMADEMY project, an assessment is related to the aims of the climate education lesson, a larger climate education module, or even a broad competence framework. Assessment in the context of climate education could be challenging because the aims for climate education are typically set holistically, or the competence framework behind the pedagogical approaches is complex. At the same time, students are guided to learn climate values, socio-emotional skills and core knowledge in the domain through engaging them in scientific and engineering knowledge practices, collaboration and construction of an educational artefact, such as posters, reports, or guidelines for responsible behaviour. 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, 2018).

A brief overview of the assessment is presented in the following.

The concept of assessment refers to the actions which are supportive of the learning process and the actions which are aimed at determining the amount and quality of the learning outcome (Black & Wiliam, 2009). The main types of assessment are the following:

- *Summative assessment*

  When an assessment action makes a judgement or grade of the performance of a student, the type of assessment is summative (Wiliam, 2000).

  Tests, exams and essays are tools for this kind of assessment.

- *Diagnostic assessment*

  A diagnostic assessment aims to determine what the student already knows before teaching. Tools for diagnostic assessment include various tests, teacher questioning and observations (Leighton & Gierl, 2007)

- *Formative assessment*

  A Formative assessment aims to provide feedback on learning-in-process and steer the process towards goals. The feedback could be given orally, adding comments to the portfolio or learning diary.

From the CLIMADEMY perspective, the summative assessment is used at the end of the learning process for evaluating students' learning against the CLIMADEMY competence framework. The diagnostic assessment aims to find the values, skills, perceptions and knowledge needed by the students in climate education. In contrast, the formative assessment is used to support the student's learning process. The feedback provided by the teacher to the students through the formative assessment helps the student to identify the development of values, attitudes, knowledge or skills where competences are not yet sufficient. In this way, they can develop their work to achieve the learning goals.

In the above CLIMADEMY competences tables, we reported different assessment tools.

3.8 Designed Activity on the pedagogical model for co-designer teachers

The following activity was designed for the co-designer teacher in the hubs. The goal of this activity is to present the pedagogical model and to share ideas with co-designer teachers about the frameworks, key messages, and suitable triggering questions in order to reason about the pedagogical model and use it in practice. In addition, the selected triggering questions can be used in teacher training activities to spark discussions about the pedagogical model and eventually analyse concrete educational materials (Chapter 4). The selection of these questions according to key messages and theoretical frameworks was part of my contribution to the project. These questions help teachers in positioning concerning content knowledge, sustainable competences, other teachers (in teacher education) and classroom dynamics.

The starting point of the activity that I and the physics educational research group of UNIBO designed is to present the SRP-TE model. This model supports teachers in understanding their role during teacher education. The co-designer teachers in designing activities for teacher education should adequately consider which role their colleagues are playing through each phase of teacher education and the related learning outcomes.

The first impression about this model collected from the Italian co-designer teachers' feedback was that the model does not consider the role of expert. The second impression was that it is a “step-by-step” structure (Figure 16). According to the co-designer opinion, mentee teachers can be more confident during teacher education due to the features of this model, namely playing different roles following a step-by-step structure without playing the role of expert on CC.

Following this, the CLIMADEMY competences framework is presented. The suitable questions identified for this part are the following:

- *Q.1 Are the activities presented in the hub aligned with the CLIMADEMY framework?*
- *Q.2 What competences do our activities aim to develop? How?*
- *Q.3 How can they be assessed?*

The CLIMADEMY competences tables of paragraph 3.6.2 can be used to help and support the teachers in answering these questions. However, these tables are not exhaustive. Therefore, teachers can enrich them during this activity.

Afterwards, the model of educational reconstruction is presented, detailing each component and key message. A list of questions is presented to co-designer teachers to support them in the process of educational reconstruction of scientific content. Selecting these questions and keeping them accessible for teachers has required discussion among all researchers involved in WP3. The PCK concept introduced in this Chapter is helpful because we intend to use the Content Representation (CoRe) tool, which is a tool for structuring pedagogical content knowledge (PCK) to make instruction coherent (Loughran et al., 2008). In particular, we in the WP3 modified the original CoRe to include the CLIMADEMY competence framework, i.e., climate attitudes and values and the views related to inquiry, creativity and action (design of solutions). This tool provides us with the following proposed list of questions:

- *Q.4 What should students learn about the topic?*
- *Q.5 What should teachers know about the topic to teach it (scientific content and students' perspective)?*
- *Q.6 What are the core ideas/big ideas/key concepts and models of the topic?*
- *Q.7 Why is it important (meaningful and relevant) for students to learn this topic?*
- *Q.8 What do you know about the students' difficulties related to the topic?*
- *Q.9 What teaching methods do you intend to use to teach the topic, and how well is the method suited for teaching the topic?*
- *Q.10 How are you going to evaluate student learning?*

During the presentation of this list, an Italian co-designer teacher said: "It is a checklist!". These words display the main goal of this list, namely, to guide the teachers in the educational reconstruction process of the content by answering the questions in the list. However, this list was just a proposal for the co-designer teachers. They can select from the list the more relevant questions for their colleagues in teacher education. Furthermore, they can rephrase them if necessary and add or avoid some questions. Examples of questions for this purpose are the following:

- *Q.11 What questions are the most relevant that we can select to produce our «checklist» to consider for the design?*
- *Q.12 What questions are the most important to discuss with your colleagues?*
- *Q.13 How can you rephrase them?*

The MER positions the teachers concerning content knowledge. The next step is to position the teachers concerning the class dynamics. However, participant structures described by Tabak & Baumgartner (2004) and presented in this Chapter are highly demanding for teacher education on Climate Change.

The Bologna group started to discuss this part with the co-designer teachers in the Italian hub through very simplified schemes to get some interesting points to present during teacher education. Specifically, during a local CLIMADEMY workshop (8th May, Opificio Golinelli), we presented different schemes about the class dynamics to the co-designer teachers and asked them to notice their differences. The first scheme (Figure 19, scheme on the left) represented the traditional way of teaching where the teacher is the only source of knowledge and the students "receive" information from the teacher. The second scheme (Figure 19 scheme on the right), represented the students working in groups and a mentor teacher which is still familiar. In contrast, the third scheme (Figure 20, scheme on the left) described a complex scenario with many interactions and external sources of knowledge.

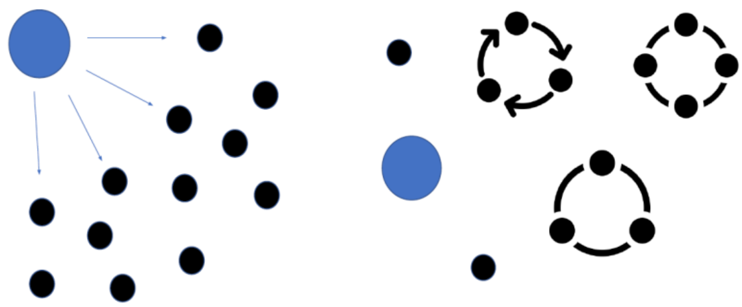


Figure 19 Traditional way of teaching: students receive the information directly and passively from the teacher. (scheme on the left). Students work in groups, and the teacher acts as a mentor. (scheme on the right)

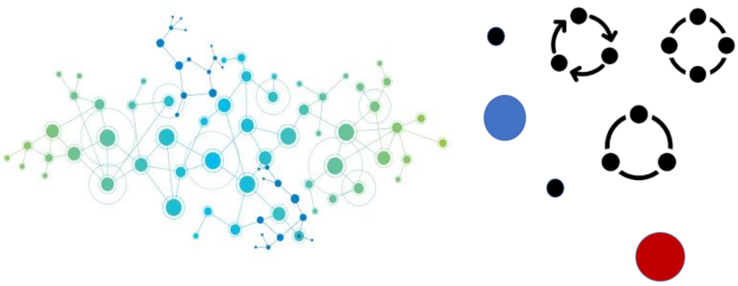


Figure 20 Different sources of knowledge and complex interactions (scheme on the left). Co-teaching scheme (scheme on the right)

In addition, we present a fourth scheme (Figure 20, scheme on the right) related to the co-teaching context that can help teachers teach interdisciplinary topics such as CC.

The first impression of the co-designer teachers was that in the second and third schemes, the interactions are represented by arrows that do not have a privileged direction. As one teacher pointed out, this means that the students will learn from the teacher as well as the teacher will learn something from the students. The idea is that students with the teacher can learn about the CC issue by studying it together. In addition, this scheme engaged co-designer teachers, opening an interesting discussion about the source of knowledge. New sources of knowledge are available, and suitable materials and videos can be found on the internet and using artificial intelligence (digital era) that could open to unexpected scenarios. The main point in this discussion was that the teachers should change their perception of their role and their relation with the knowledge. This change becomes even more necessary when social-scientific issues are considered. In these cases, teachers may not have the knowledge or solutions to the problem. During this workshop, a co-designer teacher highlighted her worries that she was often unable to answer the students' questions about modern topics such as Climate Change. This worry is likely related to the self-perception of this teacher to be an expert and to have authority over the knowledge. This discussion assures us of the importance of explicitly treating innovative and different pedagogical methods. Innovative pedagogical methods can change this situation because they can change how the teachers position themself concerning knowledge and the classroom. For this reason, pedagogical methods and principles to enact activity on CC will be one of our concerns as the Physics Education Group of Bologna University.

For this part, the following questions can lead the discussion about positioning with respect to the classroom:

- *Q.14 What is the role of the teacher?*
- *Q.15 Where or Who is the source of knowledge?*
- *Q.16 What does it mean to facilitate the discussion and the flow of knowledge?*
- *Q.17 In the case of co-teaching, who has the leadership and control of the class*?

In the end, the MERID model is presented as one that can describe mentor-mentee relationships in teacher education and teacher-student relationships in the classroom. Relevant questions that this model opens about teacher-student interactions are the following:

- *Q.18 In what teaching situations/phases do you tend to introduce topics for discussion in your classroom?*
- *Q.19 In what teaching situations/phases do you tend to encourage your students to introduce topics for discussion in your classroom?*
- *Q.20 In what teaching situations/phases do you tend to use directive practices such as assessing, advising, confirming and providing feedback in your classroom?*
- *Q.21 In what teaching situations/phases do you tend to use non-directive practices such as asking questions, developing alternatives, and summarising in your classroom?*

Chapter 4 – The Pedagogical Model in Practice

4.1 Introduction

In this chapter, I aim to show how the pedagogical model can be operatively implemented in teacher education. The main outcome of this work consists in the presentation of a "template" that was originally designed for turning the theoretical reflection on the model into a practical orientation for making the model alive in the practice.

Firstly, I start to present the main fundamental ideas of CC and students' difficulties needed in the process of educational reconstruction (paragraph 4.2). The identification of the key ideas of CC - that the CLIMADEMY project aims to convey through the educational resources collected in CLAUDI - was one outcome of the WP2.

After that, I present the template designed to design, refine, analyse, discuss or present activities for teacher education according to the pedagogical model (paragraph 4.3). The template is one of the main results of this chapter. It embeds the principles of the pedagogical instruments by representing a way to operatively translate the model into practice. Indeed, the description of the template aims to illustrate how the pedagogical model can be used in practice for teacher education on CC. It was developed using the work done so far, namely the study of the theoretical frameworks and the identification of the key messages.

Finally, I describe how the template was used to respectively reshape and design two specific activities for teacher education, selected according to the co-designer teachers' suggestions (Appendix A.2). In the Italian hub, teachers suggested a focus on educational resources to carry out interdisciplinarity activity or educational resources to carry out activity in which students work with data.

The first kind of activity I chose aims to focus on the interdisciplinary of the CC topic, incorporating different disciplines and social aspects (e.g., economic and political aspects). This activity was designed by Giulia Tasquier and Eleonora Barelli based on the Biodiesel story (Appendix A.3). However, the target of this activity was the students. My contribution was to adapt this activity to teacher education and then analyse it according to the pedagogical model (paragraph 4.4). At the same time, the activity was used to orient and test the design process of the template.

The second kind of activity uses the Atlas platform as a tool to work with CC-related data. My contribution was to show that the Atlas platform can be used as a tool for educational purposes by designing appropriate educational materials. The designed educational materials set as goals some competences of the CLIMADEMY competences framework. The analysis of these educational materials according to the pedagogical model is presented at the end of this chapter (paragraph 4.5).

4.2 Climate Change - key ideas and students' difficulties

In WP2, educational materials are collected and further developed to understand the main drivers of CC. WP3 worked closely with WP2. One result of WP2, which we used in the analysis of the activities according to the pedagogical model, was the identification of key ideas that characterised the educational material on CC.

Regarding the scientific fundamental ideas of CC from an educational point of view, they came from an analysis of the research literature on CCE. Specifically, three relevant sets of fundamental ideas are found in the literature, specifically from Jarret and colleagues (2011), McCaffrey and colleagues (2008), and Shepardson and colleagues (2011). Specifically, Jarret and colleagues (2011) conducted a Delphi study of 19 academics, researchers, and high-school teachers who have expertise in CC, as well as a comprehensive literature review (Jacobson et al., 2017). A set of ten major scientific fundamental ideas were identified and reported in the first column of Table 9. In their research, McCaffrey and colleagues (2008) consider ten concepts relating to climate atmospheric science and fossil fuel energy, reported in the second column of Table 9. Finally, Shepardson and colleagues (2011) conducted a literature review and identified 16 international studies between 1993 and 2008 that investigated how secondary students understood various ideas about global warming. Four thematic concept areas were identified in these studies: (i) *conceptions about global warming and the greenhouse effect, (ii) causes of global warming and CC, (iii) environmental impact of global warming and Climate Change, (iv) resolution of global warming and CC.*

Furthermore, Shepardson and colleagues(2011), based on their research about the student's mental models, suggest addressing the fundamental ideas reported in the third column of Table 9.

Table 9. Scientific key concepts about CC

Jarrett et al. (2011)	McCaffrey et al. (2008)	Shepardson et al. (2011)
A.1 Carbon cycle and fossil fuels; A.2 Electromagnetic spectrum; A.3 Interactions between greenhouse gases and electromagnetic radiation; A.4 Natural climate variability in the past and relationship to CO_2 levels; A.5 Differences between weather and climate; A.6 Proportions of greenhouse and non-greenhouse gases in the atmosphere; A.7 Radiative forcing capacity; A.8 Feedback; A.9 Equilibrium of energy; A.10 Conservation of energy.	B.1 Axial tilt as the "reason for seasons"; B.2 Gas/air has mass and takes up space; B.3 Plants acquire mass from carbon dioxide via photosynthesis; B.4 Fossil fuels are "buried solar energy" originally captured by living organisms; B.5 Difference between and significance of incoming UV and outgoing Infrared radiation; B.6 Greenhouse effect allows liquid water and life to exist on Earth, and human activities are "enhancing" the greenhouse effect; B.7 Ozone layer's role in the Earth system; B.8 There are significant differences between weather and climate processes and time scales and how they are studied; B.9 Small changes (atmospheric composition or temperature increase) can have a large and nonlinear effect; B.10 The Carbon Cycle and Human Dimension.	C.1 Carbon cycle, fossil fuels (energy) and greenhouse gases; C.2 Other human and natural sources of greenhouse gases; C.3 Greenhouse gases; C.4 Uniform distribution of greenhouse and atmospheric gases; C.5 Absorption and radiation of energy — energy transfer; C.6 Greenhouse effect, radiative forcing (infrared radiation) and the Earth's energy balance; C.7 Distinction between types of solar radiation and solar and terrestrial radiation; C.8 Greenhouse gases and ozone depletion; C.9 The greenhouse effect and global warming; C.10 Natural versus human sources of greenhouse gases and personal solutions and actions.

These three sets of scientific ideas or concepts are not irrelevant to each other but, in many cases, have strong overlaps.

However, the scientific fundamental ideas and concepts are not exhaustive to characterise CC and, therefore, educational material in CC.

The CLIMADEMY researchers in WP2 identified the following macro-categories of fundamental ideas and concepts:

- *How the Climate system works* (includes, for instance, the carbon cycle)
- *Interactions in the climate system - Complexity* (includes, for instance, the concept of circular causality)

- *Greenhouse effect - Greenhouse gases and aerosols* (includes, for instance, Atmospheric composition)
- *Mechanism, reasons and causes of CC* (includes, for instance, the industrial revolution)
- *Mitigation and adaptation strategies* (includes, for instance, political negotiation)

Besides the content knowledge, teachers should be informed about the students' difficulties with CC topics. Knowledge about students' difficulties with CC is needed in the educational reconstruction process since this process requires considering two kinds of knowledge, namely scientific knowledge and knowledge about students' difficulties.

McCaffrey and Buhr (2008) presented the naïve students' ideas for each climate scientific concept, while Shepardson and colleagues (2011) illustrated the students' mental models of the greenhouse effect.

Within the field of physics education research, important studies have investigated the conceptual difficulties that students can encounter in understanding the greenhouse effect and its relation to global warming. More specifically, research has revealed the following issues (Levrini & Fantini, 2013; Besson et al., 2010): *(i) infrared emission of bodies is usually not taken into account as an energy-loss mechanism, (ii) emittance, when considered, is often confused with reflectance, (iii) students tend to give absolute meaning to properties like transparency, absorptivity and emissivity, rather than seeing them as interactive properties, (iv) radiation is often confused with heat, and (v) students tend to apply temporal or linear causal reasoning for explaining process instead of causal schemes based on balancing and equilibration* (Tasquier et al., 2016).

Epistemological issues are involved in studying CC besides the above conceptual barriers. The main epistemological issues are related to the fact that CC implies non-linear models whose features are very different from the classic and mechanistic view of modelling (Pasini, 2003). Epistemological issues also arise when very basic models are used in an introduction to the greenhouse effect, which can easily leave students sceptical and detached (Tasquier, 2015a; Tasquier et al., 2014).

However, the challenge of producing citizens who feel personally involved in such a social issue is much more complex than simply enabling students to understand scientific concepts such as the greenhouse mechanism. Researchers in the social sciences have been investigating for years why citizens tend to deny CC problems and are still relatively resistant to becoming involved in it (Lorenzoni et al., 2007; Weintrobe, 2012).

The template I designed uses the WP2 study of the CC key ideas in the educational reconstruction process of contents. Teachers are invited to select the key ideas of the topic/phenomenon under investigation in order to reconstruct them for instruction. In addition, they are invited to reflect on the students' difficulties related to these key ideas.

4.3 Template to analyse, discuss or present training activities according to the pedagogical model

As said before, the WP2 analysis of key ideas is used in the designed template for the educational reconstruction of contents. The educational reconstruction is one part of the template. In the following, we present all its parts and explain its role.

The “template” represents the main outcome of this work that was originally designed for turning the theoretical reflection on the model into a practical orientation for making the model alive in the practice and, operatively, for analysing, discussing or present activities for teacher education according to the pedagogical model. Precisely, the template was designed by using the literature study and the key messages reported in Chapter Three in a creativity process.

The main features of this process can be briefly described as follows:

1) The STE-PE model can be used to structure the analysis, discussion or presentation of activities for teacher education;
2) For each phase of the STE-PE model, specific tasks can be established to achieve the learning outcomes set for teacher education on CC in which mentors and mentees have a specific role;
3) Specific key messages and certain theoretical frameworks of the pedagogical model are suitable for one phase but not others;

4) In order to use the key messages and the theoretical frameworks of the pedagogical model intuitively, suitable guiding questions can be identified;
5) The template can guide the analysis, discussion or presentation of the activity for teacher education by answering the selected questions.

The template was designed by using an existing and already well-established activity designed for CC module (Barelli, 2017; Levrini et al., 2021; I SEE project[8]; IDENTITIES project[9]), the "biodiesel activity". This activity was rethought and re-analysed following the principles of the CLIMADEMY pedagogical model. This process of re-working on a well-consolidated activity helps methodologically to focus on how to use the model. As a result of this first process, the first draft of the template emerged. This draft was discussed with the small and the big group of researchers and was refined through several steps. Once arrived to a stable version, the template was proved against a new situation, by using it to design a new activity from scratch, the "Atlas activity". Methodologically, the first part of the biodiesel activity presented in paragraph 4.4 oriented the designing process of the template as a first attempt at using the pedagogical model in practice. Then, I tested the first draft template by applying it to the second part of the biodiesel activity. Finally, I used the template to analyse an activity that I was building about the Arctic region with the specific goal of following the pedagogical model.

The final result is a template with four sections according to the number of phases of the STE-PE model (the icons used are reported in Figure 21). The STE-PE model is supposed to guide the mentor teachers to structure the activities for mentee teachers in teacher education by taking into account the multiple roles that teachers can and should play throughout their training (students, analysts, designers and implementers).

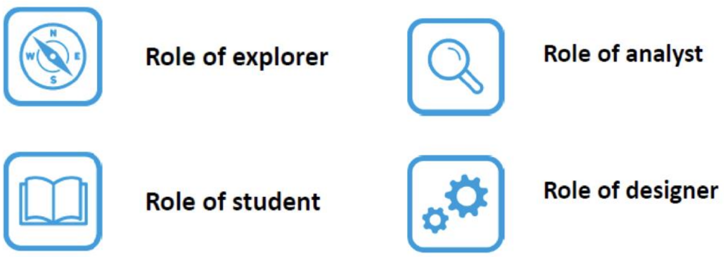


Figure 21. Icons for the template sections (https://identitiesproject.eu/)

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[8] Erasmus+ Programme (Grant Agreement n°2016-1- IT02-KA201- 024373) https://iseeproject.eu/
[9] Erasmus+ Programme (Grant Agreement n°2019-1- IT02-KA203- 063184) https://identitiesproject.eu/

In the following, I illustrate the main goal of these phases, the link with the frameworks of the pedagogical model and the suitable guiding questions.

In the **explorer phase**, the mentee explores the topic/phenomenon proposed by the mentor, focusing on which knowledge should be part of instruction and which not. In this phase, since the target is an activity for students, the mentee teacher should identify which knowledge should be used in this activity and which not. The identified guiding questions are the following:

- *What should students learn about the topic/text?*
- *What else should teachers know about this topic – not going to teach to students (the level of scientific content)?*

In the **student phase**, mentee teachers are invited to study the key concepts of the topic/phenomenon, the contexts in which this topic/phenomenon is or can be embedded, the epistemic competences that students could develop through the educational material used to carry out the activity on the topic/phenomenon, and the students' difficulties. These are key elements of the educational reconstruction process. Precisely, the key concepts are the result of the 'elementarization' process. Identifying the contexts and the epistemic competences, and considering the students' difficulties with the topic/phenomenon are key ingredients of the enrichment process. The identified guiding questions are the following:

- *What are the core ideas/big ideas/key concepts and models of the topic?*
- *What are the epistemic competences this activity can develop?*
- *In which contexts are the activity's key concepts/scientific content embedded?*
- *What are the students' difficulties with the topic/activity?*

In the **analyst phase**, the mentee has to analyse the topic/phenomenon and the related activity for students more deeply, focusing on its educational value. Therefore, besides the relevance and meaning that the activity under investigation can have for students, the CLIMADEMY competences that could be developed through the activity (targeted for students) are supposed to be identified in this phase. The identified guiding questions are the following:

- *Why is it important (meaningful and relevant) for students to learn this topic?*
- *What competences does the analysed activity aim to develop?*
- *How are these competences developed?*
- *How can they be assessed?*

Finally, in the **designer phase**, the mentee teachers can focus on implementing the activity under investigation in their classroom, adapting it or designing a different one if necessary. They are invited to think about the role of the teacher in the classroom and the source of knowledge. The participant framework and the MERID model play a relevant role in this phase. The identified guiding questions are the following:

- *Which is the source of knowledge?*
- *Which participant structure will you use to enact this activity?*
- *Which degree of directiveness and input will you use in the classroom?*

The final result is a template that guides in analysing, presenting or discussing an activity for teacher education according to the pedagogical model.

In the following paragraph, I present some activities and show how these activities could be analysed according to the pedagogical model, following the guide described above. These are examples for mentor teachers to show how the pedagogical model can be used in practice for teacher education.

4.4 The Biodiesel Activity

In this paragraph, I illustrate how to use the template to analyse the biodiesel activity designed by Giulia Tasquier and Eleonora Barelli. For clarity, the biodiesel activity is divided into two sub-activities. The first requires understanding a scientific text and building a causal map, while the second focuses on the circular causal concept. In paragraph 4.4.1, I present and analyse the first biodiesel sub-activity, while in paragraph 4.4.2, the second one. The analysis has required adapting the biodiesel activity for teacher education by considering the different roles that mentor teachers and mentee teachers are supposed to play during this activity and the learning outcomes that we expect to achieve through this activity in teacher education. The educational material to carry out the two sub-activities is reported in Appendix A.3.

4.4.1 Part One - The biodiesel text and the causal map

This first part of the biodiesel activity is built on a scientific text that Giulia Tasquier and Eleonora Barelli have written, named the ‘Biodiesel Story’ (Appendix A.3.1). This text treats the most important aspects of biofuel use and production with a clear objective: to offer the students a text on which they can exercise to recognise and abstract (extract) the logical and causal structure of the phenomena described in it. This scientific text situates the specific theme of biofuel within the more general issue of transport, which in turn is related to the even broader problem of CC mitigation (Barelli, 2017). Although the fact that the issue of biofuels is often treated in terms of pros and cons, advantages and disadvantages, the authors avoided mentioning these words in the text, limiting it to detail the cause-effect relationships without making it too explicit (in the sense that authors of the text avoid using expressions like ‘this causes this’).

Specifically, the students should read the Biodiesel Story and build a map that summarises the cause-effect net that the text displays. In the text, two main areas are identified: one is related to the use of biodiesel, while the other is related to its production. The arrows indicate the different levels of causality. The map built on the text and proposed by the authors is reported in Figure 22.

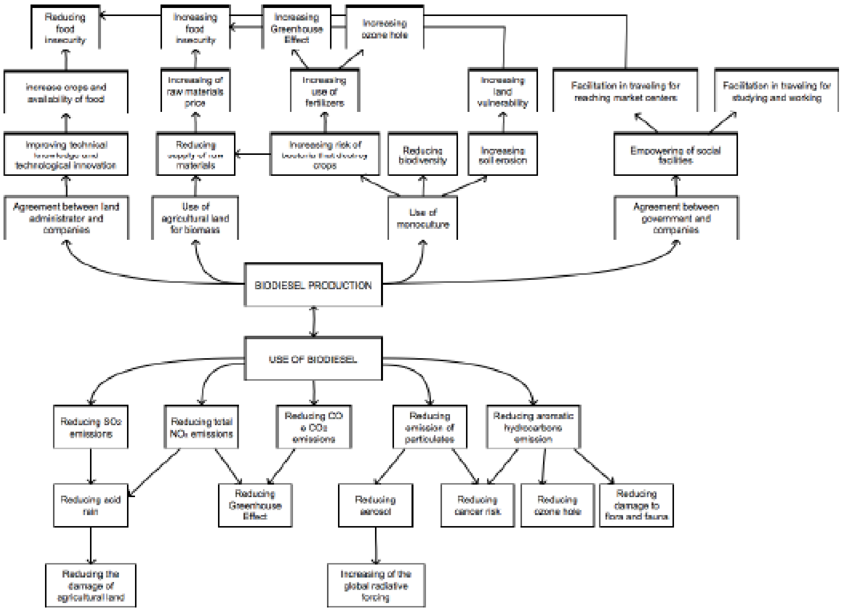


Figure 22. The proposal of the map drawn starting from the text of the "Biodiesel story" (see Annex A.2. for an enlarged version)

The activity described above was built for students. I adapted it to teacher education, describing the role of the mentor teacher and the mentee teachers. The learning outcome of this activity adapted for teacher education is to equip mentee teachers with new tools to teach CC, specifically, building and using scientific text and causal maps.

In the following, the adapted activity for teacher education is analysed according to the pedagogical model through the template described in this chapter.

[*In the following I present an overview of the biodiesel activity for teacher education. Specifically, according to the SRP-TE model, I describe the mentee teacher role, the expected mentee learning outcomes, and the role of the mentor teacher*]

1. EXPLORER

Mentee's role: The teacher mentee is stimulated by initial questions to search for information about a specific topic (i.e., use and production of biodiesel). This task can be done in a group of teachers, in which they share ideas and knowledge related to the scientific content.
Mentee learning outcomes: Get information about the specific topic (i.e., biodiesel use and production), and identify what should be content for instruction and what not.
Mentor's role: The mentor introduces topics and asks questions (Initiator).

2. STUDENT

Mentee's role: The teacher mentee does the activity as designed for students. Expressly, the teacher understands the scientific text about biodiesel and builds the linear causal map. During this activity, the teacher mentees can appropriate the scientific knowledge and simultaneously recognise the students' difficulties in understanding the text/topic and building the linear causal map.
Mentee learning outcomes: Understand the scientific concepts related to the topic. Find out the students' difficulties.
Mentor's role: The mentor uses directive practices and skills to address topics

3. ANALYST

Mentee's role: The teachers' mentees analyse the text and the casual map as educational material for the lesson. They aim to identify its potential in terms of educational value and CLIMADEMY competences.
Mentee learning outcomes: Recognise the educational value of an interdisciplinary activity. Consider sustainability competences as the ultimate goal of instruction (which competences develop and how to develop and assess them in the classroom).
Mentor's role: The mentor uses mainly directive skills to discuss the objectives of the activity analysed set as learning outcomes and sustainable competences (Imperator or Advisor).

4. DESIGNER

Mentee's role description: The teacher mentee is asked to adapt the analysed activity for their class and design a new one.
Mentee learning outcomes: Learn how to position themselves with respect to the classroom in teaching such activity according to classroom particularities.
Mentor's role: Mainly, the mentor uses no directive skills in this phase, in which the classroom particularities and teacher style are relevant (Encourager or Initiator).

[In the following four boxes I describe in detail each phase of the teacher education (explorer, student, analyst and designer), presenting the task, the guiding questions and examples of possible answers to these questions]

2. Explorer

Task

Teacher mentees are invited to share ideas in groups about:
- The idea of causality, i.e. the kind of anthropogenic causes that play a crucial role in the domain of greenhouse gas emissions, among which food consumption (e.g. related to agriculture and livestock farming), energy consumption (e.g. related to electricity and heat production) and transports;
- Biomasses and fossil fuel emissions
- Biomasses cultivation in terms of agricultural aspects and/or economic and political aspects (e.g. soils' vulnerability, food insecurity, etc.).

The mentor introduces questions to foster the discussion.
Specifically, teacher mentees should discuss in groups what the students should learn about the topic and what knowledge is needed to teach it, answering the following guide questions.

Guiding questions and examples of possible answers

What should students learn about the topic/text?

Greenhouse gasses and biodiesel emissions versus fossil fuel emissions. Impacts of Biomasses Use and Production on the Environment, including social and political aspects.

What else should teachers (mentees) know about this topic – not going to teach to students (the level of scientific content)?

The teacher should know in detail the chemical reactions that can occur with the components of the atmospheric system. The teacher should know about fossil fuel emissions in order to compare them with biodiesel emissions.

2. *Student*

Task

Individually work on the biodiesel story. Specifically, understand the text and build the linear causal map. After that, list the key concepts underlying the text and related to the causal map. Identify which difficulties the student can encounter in doing this activity and in which contexts the key concepts are used to make sense to the students.

Guiding questions and examples of possible answers

What are the core ideas/big ideas/key concepts and models of the topic?

Carbon cycle, fossil fuels (energy) and greenhouse gases. Other human and natural sources of greenhouse gases. Plants acquire mass from carbon dioxide via photosynthesis. Greenhouse gases (CO, CO_2, N_2O). Greenhouse effect, radiative forcing (infrared radiation) and the Earth's energy balance. Proportions of greenhouse and non-greenhouse gases in the atmosphere. Radiation forcing. Greenhouse gases and ozone depletion. Feedback Linear causality vs circular causality.

What are the epistemic competences this activity can develop?

- Ability to recognise important disciplinary details and situate them into the global picture;
- Ability to break down and rebuild information into different logical, causal and temporal structures;
- Ability to argue and recognize causal structures in a scientific argument (in the biodiesel story, the enrichment is the casual structure, i.e., knowledge and concepts are presented organized to acknowledge the causal structure);
- Ability to identify different logical relationships (e.g. differentiate between problems, objectives and solutions, differentiate between pros and cons).

In which contexts are the activity's key concepts/scientific content embedded?

Use of biomasses for Climate Change mitigation. Environmental, social and economic aspects of the use and production of biofuels.

What are the students' difficulties with the topic/activity?

Students could tend to organise information in lists and/or advantages/disadvantages 'a-priori' judgements. The temptation of premature judgment and clusterisation is very strong in the students when they analyse the biodiesel text in order to extract the relevant information and build the causal links. (Barelli, 2017)

3. *Analyst*

Task

Working in small groups, analyse the activity from an educational point of view. Firstly, identify the student's learning outcomes and list them. Secondly, identify sustainability competences that can be developed, the methods to build them and the tools to assess them.

Guiding questions and examples of possible answers

Why is it important (meaningful and relevant) for students to learn this topic?

Students learning outcomes (educational value):

Become able to analyse scientific texts by recognising the causal relations made by links and nodes;
The interdisciplinarity of the topic: links between STEM (Science, Technology, Engineering and Maths) disciplines and SSH (Social Sciences and Humanities) disciplines, that in this case, include for example the socio-political dimension;
The interdisciplinarity competences needed to deal with a wicked problem.

What competences does the analysed activity aim to develop?

Value and attitudes

Promoting nature*: Students know that our well-being, health and security depend on the well-being of nature. Examples from the text: increasing food insecurity, and reducing cancer risk. (K) Knows about the main parts of the natural environment and that living organisms and non-living components are closely linked and depend on each other. (K) Knows that our well-being, health and security depend on the well-being of nature. (K) Knows that humans shape ecosystems and that human activities can rapidly and irreversibly damage ecosystems. (K) Knows about the need to decouple production from natural resources and well-being consumption. (S) Can assess own impact on nature and consider the protection of nature an essential task for every individual. (A) Cares about a harmonious relationship existing between nature and humans. (A) Is appreciative of nature's role in our wellbeing, health and security*
Supporting fairness*: To support equity and justice for current and future generations. Example from the text: Production of biofuels implies an increase in the price of raw materials in the Third World. (K) Knows that ethical concepts and justice for current and future generations are related to protecting nature. (S) Can apply equity and justice for current and future generations as criteria for environmental preservation and the use of natural resources. (A) Has a sense of belonging to common humanity and of solidarity with future generations. (A) Is committed to respecting the interests of future generations.*

Justice and collaboration: *Understanding and aiming for equality, equity, and justice (K) Understands equality, equity and justice related to the unequal nature of CC. (S) Listen and treat people and nature in an equal and caring way. (A) Aims for justice and equality/equity*

Scientific inquiry

Systems thinking: *To approach a sustainability problem from all sides; to consider time, space and context in order to understand how elements interact within and between systems. Example from the text: production of biodiesel led to reducing biodiversity, increasing raw materials price and so on.*

(K) knows that every human action has environmental, social, cultural and economic impacts. (K) Knows that human action influences outcomes across time and space, leading to positive, neutral or negative results. (S) Can describe sustainability as a holistic concept that includes environmental, economic, social and cultural issues. (S) Can assess interactions between environmental, economic, social and cultural aspects of sustainability action, events and crises. (A) Has a holistic grasp of connections and interactions between natural events and human actions. (A) Is concerned about the short- and long-term impacts of personal actions on others and the planet.

Problem framing: *Related to the necessity to look at sustainability problems from different stakeholder perspectives and the skill of establishing a transdisciplinary approach to framing sustainability challenges. Example from the text: relation between companies, government and administrators.*

(K) Knows that to identify fair and inclusive actions, it is necessary to look at sustainability problems from different stakeholders' perspectives. (S) Can factor in perspectives of multiple stakeholders, considering all life forms and the environment to frame current and potential sustainability challenges. (S) Can establish a transdisciplinarity approach to framing current and potential sustainability challenges. (A) Is committed to presenting a sustainability problem as a complex one rather than oversimplifying it.

Critical thinking: *Related to the skills of analysing and assessing arguments, ideas, actions and scenarios to determine whether they are in line with evidence and values in terms of sustainability. Examples from the text: consider the production of biodiesel rather than just the use of biodiesel.*

(K) Knows that tackling unstainable patterns requires challenging the status quo, at the individual and collective level, by organisations and in politics. (S) Can reflect on the roots and motives of decisions, actions and lifestyles to compare individual benefits and costs with societal benefits and costs. (A) Is willing to accept and discuss sustainability questions, issues and opportunities.

CC scientific orientation: *Bases knowledge of scientific information, understands scientific CC-related information, and knows the factors that led to the present state and the effects of (climate) actions on the future. Information about the effects of the use and production of biodiesel*

Creativity

Adaptability: *Ability to cope with trade-offs in sustainability, e.g. environmental impacts and social outcomes as well as economic aspects.*
(K) Knows about risks associated with transformations of the natural environment by humans. (S) Can identify and adapt to different lifestyles and consumption patterns to use fewer natural resources (A) Is comfortable considering sustainable practices and try alternative solutions.
Exploratory thinking: *To adopt a relational way of thinking by exploring and linking different disciplines.*
(K) Knows that sustainability problems must be tackled by combining different disciplines, knowledge cultures and divergent views to initiate systemic change. (S) Can combine knowledge and resources to tackle sustainability challenges. (A) Is committed to considering sustainability challenges and opportunities from different angles

Action

Justice & collaboration: *K: Understands equality, equity, and justice related to the unequal nature of Climate Change. Examples from the text: the conversion of terrains destined to the growing of plantations into areas where biodiesel is produced implies an increase of the price of raw materials in the Third World.*

[*The sustainability competences in terms of knowledge, skills and attitude are described in the GreenComp (Bianchi et al., 2022) and the ClimComp*]

How are these competences developed?

Reflection, dialogue, discussion;
Learning in small groups, explaining to others, discussing with others;
Envisioning;
Collaboration with society, project management, group leadership.

How can they be assessed?

Using casual maps for a summative assessment. Specifically, build a causal map from another text;
Essay about sustainability value and attitude;
Report or videos about possible future scenarios.

4. Designer

<u>Task</u>

Individually, the teacher adapts the analysed activity according to their classroom needs, thinking about its implementation. Answer the following guiding questions to express the source of knowledge and the role of the teacher in terms of accountability, knowledge distribution, discourse pattern, degree of input, and degree of directiveness. After that the teacher exchanges ideas with their colleagues and mentor. Finally, the teacher is invited to design a new activity.

<u>Guiding questions and examples of possible answers</u>

Which is the source of knowledge?

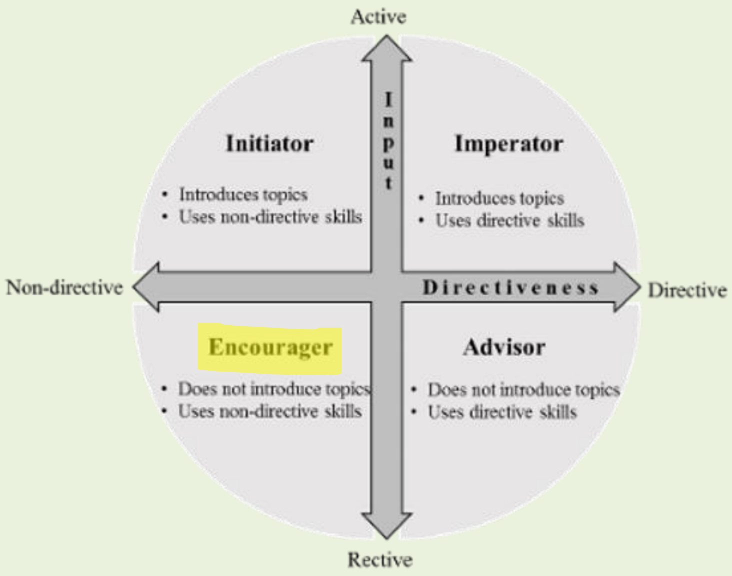
The written text (e.g. biodiesel story) and the notes with links and extra sources given for deepening the different parts of the text.

Which participant structure will you use to enact this activity?

Mentor, partner or co-teaching.

Which degree of directiveness and input will you use in the classroom?

The activity should not require that the teacher introduce topics or use directive skills. Encourager is likely the suitable role for this activity.



4.4.2 Part Two - Feedback loops

The feedback mechanism is introduced in the second sub-activity, showing that some links can be enriched in the map built in the first part if one considers the underlying feedback loops. The goal is to build proper skills related to circular causality. For this purpose, the students are invited to carry out two tasks. The first task of this sub-activity consists of considering some feedback loop schemes, presented in Appendix A.3.3. The students detail them in an extended form. Specifically, each group of students receive two feedback loops, and after having provided a detailed description of the phenomena summarised in the schemes, they have to situate the loops they received in the map of the biofuel issue (Barelli, 2017). The authors' proposed map, in which all the feedback areas are highlighted, is reported in Figure 23 and Appendix A.3.4. The second task of this sub-activity consists of the request to find in the map other possible loops different from those given in the previous phase related to the issue. Students are asked to detail the loops found in an extended way and to represent them in a scheme.

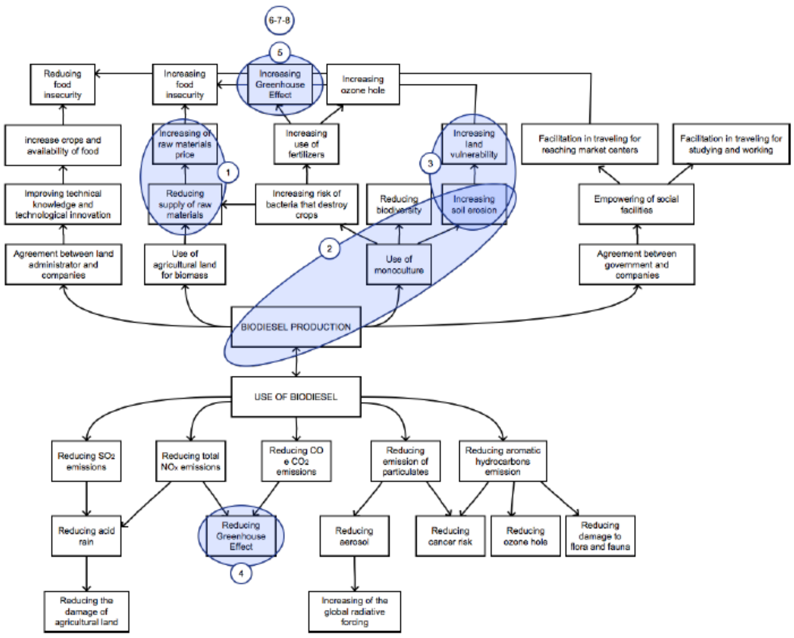


Figure 23. The authors' proposed map where the feedback areas have been highlighted (see Appendix A.2.4 for an enlarged version)

As well as for the first sub-activity, I adapted the second sub-activity designed for students to the teacher education context, detailing mentor and mentee teacher roles and the learning outcomes.

The analysis of this adapted activity for teacher education is illustrated in the following.

[*In the following box, I present an overview of the activity for teacher education. Specifically, according to the SRP-TE model, I describe the mentee teacher role, the expected mentee learning outcomes, and the role of the mentor*]

1. EXPLORER

Mentee's role: Teachers search and share information about the concept of circular causality and its role in the climate system.

Mentee learning outcomes: The teacher knows that the climate is a complex system and knows specifically about the circular causality concept. They are aware of students' difficulties with this concept.

Mentor's role: The mentor introduces topics and asks questions (Initiator).

2. STUDENT

Mentee's role: The teacher does the activity as designed for students. Expressly, teachers describe some feedback loops provided by the mentor and situate them in the linear map. Finally, search for and define other feedback loops. During this activity, the teacher can appropriate the scientific knowledge and simultaneously recognise the students' difficulties.

Mentee learning outcomes: Understand the scientific concepts related to the topic. Find out the students' difficulties.

Mentor's role: The mentor uses directive practices and skills to address topics (Imperator or Advisor)

3. ANALYST

Mentee's role: The teachers analyse the text and the casual map as educational material for the lesson. They aim to identify its potential in terms of educational value and CLIMADEMY competences.

Mentee learning outcomes: The teacher is able to recognize the educational value and sustainability competences achievable through an activity built on a complex concept such as the concept of circular causality.

Mentor's role: The mentor uses mainly directive skills to discuss the objectives of the activity analysed set as learning outcomes and sustainable competences (Imperator or Advisor).

4. DESIGNER

Mentee's role: The teacher is asked to adapt the analysed activity for their class. The teacher designs a new activity.

Mentee learning outcomes: Learn how to position themselves with respect to the classroom in teaching such activity according to classroom particularities.

Mentor's role: Mainly, the mentor uses no directive skills in this phase, in which the classroom particularities and teacher style are relevant (Encourager or Initiator).

In the following four boxes, I presented each phase in detail, specifying the task and the guiding question. In addition, I provided examples of possible answers.

1. Explorer

<u>Task</u>

Trainee teachers are invited to share ideas about:
- Concepts of feedback and of linear and circular causality;
- Complexity and complex systems properties.

The teacher trainer introduces questions to foster the discussion.
Specifically, teachers should discuss in groups what the students should learn about the topic and what knowledge is needed to teach it.

<u>Guiding questions and examples of possible answers</u>

What should students learn about the topic/text?

The students learn about the difference between linear and circular causality and the difference between positive and negative feedback. They already know the main feedback loops related to the "biodiesel story".

What else should teachers know about this topic – not going to teach to students (the level of scientific content)? [Teacher knowledge]

The teachers know about complexity and complex properties. They acknowledge the relevance of feedback loops in the CC. They are informed about feedback loops related to the biodiesel story.

2. Student

Task

Individually work on the key concept. Specifically, the teacher mentees receive exemplary feedback loops related to the context of the story and after having explained them as detail mechanisms and identified them as positive or negative, they have to position them in the global map by giving them a meaning related to the global picture. Finally, they have to invent other possible feedback loops (at least one negative and one positive) to relate to the map (and the text).
Finally, the trainee teachers identify which difficulties the student can encounter in doing this activity, the epistemic competences and in which contexts the key concept is used to make sense to the students.

Guiding questions and examples of possible answers

What are the core ideas/big ideas/key concepts and models of the topic?

Concept of circular causality.

What are the epistemic competences this activity can develop?

- *Ability to recognise different levels of causality;*
- *Ability to reason in terms of balancing and dynamical equilibrium (negative feedback);*
- *Ability to use the global picture for identifying and explaining details as well as to use details for giving meaning to the global pictures;*
- *Ability to differentiate between pros and cons.*

In which contexts are the activity's key concepts/scientific content embedded?

- *Physics-related feedback: For instance, the link between the greenhouse effect, the atmosphere's absorbance and the Earth-Atmosphere system's temperature.*
- *Agricultural-related feedback: For instance, the link between fertilizer, plant growth, land vulnerability and soil erosion.*
- *Economic-related feedback: For instance, the link between price, demand and supply of raw material.*

Which are the students' difficulties with the topic/activity

Students could tend to organise information in lists and/or advantages/disadvantages 'a-priori' judgements. The temptation of premature judgment and clusterisation is very strong in the students when they analyse the biodiesel text in order to extract the relevant information and build the causal links. (Barelli, 2017)

3. Analyst

Task

Working in small groups, teachers' mentees analyse the activity from an educational point of view. Firstly, identify the student's learning outcomes. Secondly, they identify which sustainability competences that can be developed, the methods to build them and the tools to assess them.

Guiding questions and examples of possible answers

Why is it important (meaningful and relevant) for students to learn this topic?

Become able to distinguish between linear and circular causality within the scientific texts, recognizing the nature of the causal links and individuating possible feedback loops that can be found starting from the text.
Connect physics aspects (greenhouse effect, temperature, radiation) with environmental, social and economic factors.

What competences does the analysed activity aim to develop?

Scientific inquiry

Systemic thinking*: (K) Knows that every human action has an environmental, social, cultural and economic impact. (K) Knows that human action influences outcomes across time and space, leading to positive, neutral and negative results. (K) Knows the main concepts and aspects of complex systems (specifically the feedback loops). (S) Can describe sustainability as a holistic concept that includes environmental, economic, social and cultural issues. (S) Can assess interactions between environmental, economic, social and cultural aspects of sustainability action, events and crises. (S) Can assess how humans and nature interact across space and time. (S) Can identify in a system those challenges and opportunities that have the greatest potential to trigger change for sustainability (A) Has a holistic grasp of connections and interactions between natural events and human actions. (A) Is concerned about the short- and long-term impacts of personal actions on others and the planet.*

Problem framing*: (K) Knows that current or potential sustainability problems can quickly evolve and therefore need to be frequently redefined and reframed. (S) Can establish a transdisciplinarity approach to framing current and potential sustainability challenges. (A) Is committed to presenting a sustainability problem as a complex one rather than oversimplifying it.*

Creativity

Future literacy*: To envision alternative sustainable futures.*
(K) Knows that effects caused by humans play a major role when mapping alternative and preferred future scenarios. (S) Can analyse and evaluate futures and their opportunities, limitations and risk. (S) Can anticipate future implications by looking at past trends and present conditions. (A) Has a long-term perspective when planning, assessing and evaluating sustainability action. (A) Is concerned about the impact of one's own action on the future.

Adaptability*: To manage challenges in complex sustainability situations*
(K) Knows that human actions may have unpredictable, uncertain and complex consequences on the environment.

Exploratory thinking*: To adopt a relational way of thinking by exploring and linking different disciplines.*
(K) Knows that sustainability problems must be tackled by combining different disciplines, knowledge and divergent views to initiate systemic change. (A) Is committed to considering sustainability challenges and opportunities from different angles.

[*The sustainability competences in terms of knowledge, skills and attitude are described in the GreenComp (Bianchi et al., 2022) and the ClimComp*]

How are these competences developed?

For example:
Learning in small groups, explaining to others,
Envisioning

How can they be assessed?

For example:
- Complete given feedback loops with missing boxes;
- Compare different scenarios where some feedback loops are stopped by human actions;

4. Designer

Task

Individually, the teacher mentee adapts the analysed activity according to their classroom needs, thinking about its implementation. Answer the following guide questions to express the source of knowledge and the role of the teacher in terms of accountability, knowledge distribution, discourse pattern, degree of input, and degree of directiveness. After that the teacher mentee exchanges ideas with their colleagues and teacher trainer. Finally, the trainee teacher is asked to design a new activity based on the circular causality concept.

Guiding questions and examples of possible answers

Which is the source of knowledge?

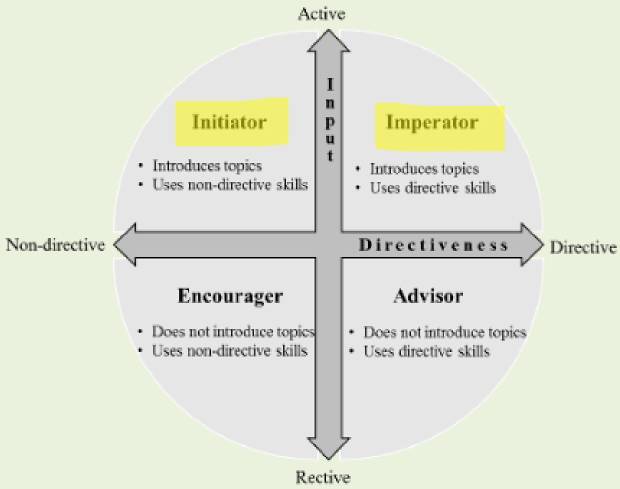
The written text (e.g. biodiesel story), the notes with links and extra sources provided for deepening the different parts of the text, the final map, the provided feedback loops, and the mentor.

Which participant structure will you use to enact this activity?

Mentor, partner or co-teaching.

Which degree of directiveness and input will you use in the classroom?

Active (Initiator or Imperator)
This part of the activity could require that the teacher should help students with information and suggestions.



4.5 The Atlas activity

In this paragraph, I briefly presented the Interactive Atlas platform, an existing tool I used to work with CC data for educational purposes.
I decided to design educational materials to carry out an activity on CC data for two reasons. Firstly, during the discussion with Italian co-designer teachers, the importance of working with data emerged strongly (Appendix A.2). Secondly, the science education research underlined that one central skill of the twenty-first century is the ability to work with data. In paragraph 4.5.2, I described the educational materials designed to carry out the activity for students. In paragraph 4.5.3, I illustrate the potential of this activity for teacher education and report the analysis of the designed activity for teacher education according to the pedagogical model.

4.5.1 The "Interactive Atlas" platform

The interactive Atlas is a product of the IPCC Sixth Assessment Report. It allows analysis of global and regional information on past trends and future climate changes through a wide range of maps, graphs and tables generated in an interactive manner and building on six basic products (time series, stripes, annual cycle plots, global warming level plots, scanner plots, tabular information). The interactive Atlas includes both atmospheric (daily mean, minimum and maximum temperature, precipitation, snowfall and wind) and oceanic (sea surface temperature, pH, sea ice and sea level rise), as well as some derived extreme indices and a selection of CIDs (used in Chapter11 and Chapter 12 of IPCC report respectively). Both essential variables and indices/CIDs are computed for CMIP5, CMIP6, and CORDEX model projections. The calculations are performed on the original model grids, and results are interpolated to the reference regular grids at horizontal resolutions of 2° (CMPI5), 1° (CMPI6) and 0.5° (CORDEX) (Iturbide et al., 2021). For CMIP5 and CORDEX, information is available for historical and *representative concentration pathways* (RCP2.6, RCP4.5 and RCP8.5)**.** While for CMIP6, information is available for historical and *shared socioeconomic pathways* (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5).

Representative Concentration Pathways (RCPs) are a set of time series of plausible future concentrations of greenhouse gases, aerosols, and chemically active gases, as well as land use changes (Moss et al., 2008; Moss et al., 2010; van Vuuren et al., 2011). The RCPs are used for projections of the future climate in CMIP5. They are identified by their approximate anthropogenic radiative forcing by 2100 (relative to 1750, in W m^{-2}). Shared Socioeconomic pathways (SSPs) complement the RCPs with varying socioeconomic challenges to adaptation and mitigation (e.g., population, economic growth, education, urbanisation, and the rate of technological development). The SSPs describe the following five alternative socioeconomic futures: *sustainable development* (SSP1), *middle-of-the-road developmen*t (SSP2), *regional rivalry* (SSP3), *inequality* (SSP4) and *fossil-fuelled development* (SSP5). The RCPs set plausible pathways of greenhouse gas concentrations and climate changes that can occur, and the SSPs set the stage on which reductions in emissions will or will not be achieved within the context of the underlying socioeconomic characteristics and shared policy assumption of that world. The combination of SSP-based socioeconomic scenarios and RCP-based climate projections provides an integrative frame for climate impact and policy analysis.

In the Atlas platform, the scenarios are referred to as "SSPx-y", where "SSPx" refers to the Socio-economic Pathway describing the socio-economic trends underlying the scenario, and "y" refers to the approximate level of radiative forcing (in watts per square metre, or W m^{-2}) resulting from the scenario in the year 2100.

All products (maps, graphs and tables) are available for different reference periods of analysis, either time slices (2021-2040, 2041-2060 and 2081-2100) and GWLs (1.5°C, 2°C, 3°C, 4°C) with changes relative to a number of alternative **baselines** (for instance 1850-1900 pre-industrial or 1995-2014 recent past baseline).

4.5.2 Arctic activity designed for students

The main goal of science education has changed throughout the years, shifting from the traditional approach of educating future scientists and engineers to making all students scientifically literate (transition from Vision I to Vision II of scientific literacy). Specifically, graph interpretation competences are essential to understand today's world and to be scientifically literate. (Glazer, 2011).

I designed educational materials to carry out an activity in secondary school using CC-related data. The educational material consists of a scientific text about the Arctic region, in which some information is missing (the text that I wrote is presented in Appendix 4). The scientific text was built based on the information reported in the Six Assessment Report of the IPCC. Specifically, the scientific text is a summary report on the CC that involves the Arctic region. It is articulated in the following five sections:

- Introduction to the Arctic region;
- Temperature and precipitation changes in the past for the Arctic region;
- Temperature and precipitation changes projections under several scenarios for the Arctic region;
- Sea ice concentration loss concerning the Arctic Ocean up to 2100;
- Global Anthropogenic emission of CO_2.

Students are invited to fill out this report using the data from the IPCC Atlas platform. To address this task, the student needs to learn to use the Atlas platform and work with the data that the platform can display. Precisely, they are supposed to extract the data by choosing the appropriate setting parameters (i.e., region, dataset, variable, quantity, scenario and season) and the suitable basic products of the platform (i.e., time series, stripes, annual cycle plots, global warming level plots, scanner plots, tabular information). Which parameters to select and which products refer to is not always evident (for instance, when the information needed is about the cold season, the students can choose to get information directly from the graph by selecting a specific period or selecting the data from the seasonal stripes for the months of interest). Furthermore, more than the Atlas platform is needed to have the missing information because an elaboration of data is required (for instance, an average over the year or building a graph with several scenario projections). In order to get some information and fill the text, it is also required to construct graphs and tables. The interpretation of data and the ability to construct graphs and tables are central to the process and product of science (Bowen & Roth, 2005). Despite the importance of graph reading competence, this is a complex activity, and graph interpretation is affected by many factors, including the aspects of graph characteristics, the content of the graph and viewers' prior knowledge (Galzer N., 2011).

4.5.3 Arctic activity for teacher education

The Arctic activity has the potential to be used in the context of CLIMADEMY teacher education. Firstly, this activity is relevant in teacher education because it introduces a new tool to work on CC-related data with students. One teacher's need to teach CC is to have new tools and methods, as emerged from the investigation about the teachers' needs (Chapter Two). The Atlas platform is a useful educational resource that lets students intuitively and interactively navigate CC-related data. Secondly, in science education research, Bowen and Roth (2005) found that pre-service teachers have difficulties with graph interpretation tasks commonly used by scientists in their everyday work. Glazer (2011) argued that an obstacle is the lack of awareness among teachers with regard to difficulties that students have with graphing. This kind of obstacle can be overcome with teacher education that focuses also on students' difficulties.

In the context of teacher education according to the pedagogical model, the teacher can start to explore the Atlas platform and complete easy tasks; then, the teachers should learn about the scientific content (for instance, CC in the Arctic region), analyse the activity from an educational point of view and, finally adapt the activity for its implementation in their classrooms and design a new one.

In the developing process of the educational material to carry out this activity, it is possible to recognise the SRP-TE steps as well. I started to explore the Atlas platform and learn this tool. Then, I learnt about the Arctic region, studying the IPCC report and using the Atlas platform. After this step, I chose the key concepts and fundamental ideas that I wanted to include in the activity. Therefore, the fundamental ideas of scenario, feedback, and CC evidence (changes in temperature, precipitation and sea ice extended) become my "blocks" from which to build the tasks of the activity to build. However, the fundamental ideas and the key concepts need to be understood by the student and are supposed to have educational potential. For this reason, I decided to enrich the content and the key concepts. First, instead of having some tasks to accomplish, I decided to build a scientific text in which some information is missing. This choice enriches the activity because the students, to complete the text, need to understand the scientific text and extract from the text the suitable setting of the Atlas platform to complete the text correctly. Furthermore, to complete the text, it is necessary to use different representations of data, specifically tables and graphs. This choice enriches the activity because it considers the students' difficulties in using different representations of data, reading and interpreting graphs. It is worth noticing that in this phase, two kinds of knowledge are considered in designing an activity, namely the scientific content knowledge and the knowledge about the students' difficulties, according to the educational reconstruction model. The CLIMADEMY competences are also a criterion to select key concepts and fundamental ideas in the process of "elementarization". The key concepts I chose were compatible with some competences I aimed to develop through this activity. Specifically, the target competences belong mainly to the scientific inquiry group. However, focusing on different scenarios allows students to develop competences related to the future (creativity competences), and it is also a hyperlink to have additional activity on creativity and action competences (see paragraph 4.5.5). The feedback loop, synthetically treated in the scientific text, can also be a hyperlink for a focusing activity on the concept of circular causality, opening the way to complexity competences. Therefore, even if not all competences can be developed through an activity based on the Atlas platform, it is possible to use hyperlinks and designed complementary activities to develop other competences or focus on some key concepts. In the classroom, the designed activity can be done in a group of students with a teacher who acts as a mentor or partner. The teacher should use directive skills to introduce the platform and help students complete easy tasks. However, when students explore the Atlas platform, the teacher should be open to topics presented by students. Finally, when the students get used to the Atlas platform, the teacher can shift through less directive skills and practice.

In the following I present the analysis of this activity used in the context of teacher education and according to the pedagogical model.

[*In the following box, I present an overview of the activity for teacher education. Specifically, according to the SRP-TE model, we describe the teacher-mentee role, the expected mentee learning outcomes, and the role of the mentor*]

1. EXPLORER

Mentee’s role: The teacher mentee is stimulated by initial questions about the role of data in CC, sharing ideas and knowledge. After that, the teachers are asked to find some data from the Atlas (simple tasks provided by the mentor).

Mentee learning outcomes: Know about the IPCC report and the Atlas platform. Learn to use the Atlas platform.

Mentor’s role: The mentor introduces topics and asks questions (Initiator).

2. STUDENT

Mentee’s role: The teacher does the Arctic activity. During this activity, the teacher can appropriate the scientific knowledge about the Arctic region and simultaneously recognise the students' difficulties in extracting data from the Atlas platform, make sense of them, and use different representations of data (tables and graphs)

Mentee learning outcome: Learn the scientific content about the CC in the Arctic region. Find out the students’ difficulties in working with data.

Mentor’s role: The mentor uses directive practices and skills to address topics (Imperator or Advisor)

3. ANALYST

Mentee’s role: The teachers analyse the educational resources to carry out this activity from an educational point of view. They aim to identify its potential in terms of educational value and CLIMADEMY competences.

Mentee learning outcomes: Recognise the educational value of an activity based on data. Consider sustainability competences as the ultimate goal of instruction (which competences develop and how to develop and assess them in the classroom). Learn that ATLAS can be a useful tool to teach CC.

Mentor's role: The mentor uses mainly directive skills to discuss the objectives of the activity analysed set as learning outcomes and sustainable competences (Imperator or Advisor).

4. DESIGNER

Mentee’s role: The teachers are asked to adapt the analysed activity for their class. Specifically, they consider its implementation in the classroom.

Mentee learning outcome: Learn how to position themselves with respect to the classroom in teaching such activity according to classroom particularities.

Mentor’s role: Mainly, the mentor uses no directive skills in this phase, in which the classroom particularities and teacher style are relevant (Encourager or Initiator).

[In the following boxes I describe in detail each phase of the teacher education (explorer, student, analyst and designer), presenting the tasks, the guiding questions and examples of possible answers to these questions]

1. Explorer

Task

The mentee teachers are invited to share ideas and knowledge about the role of data in CC, discussing an activity based on data, such as the Arctic activity to teach CC. In this phase, the mentor introduces questions to foster the discussion. After that, the mentor presents short tasks in which the teachers work with the Atlas platform. Finally, the Arctic activity is presented, and teachers discuss what teachers should know to teach it and what students should learn about it. Specifically, they are asked to answer the following guiding questions.

Guiding questions and examples of possible answers

What should students learn about the topic/text?

Evidence of CC. Feedback. Historical changes in temperature and precipitation as pieces of evidence of CC. Future projection in temperature, precipitation, and sea ice concentration in the Arctic region according to different scenarios. The global anthropogenic CO2 emission. The risks and impacts of CC.

What else should teachers (mentees) know about this topic – not going to teach to students (the level of scientific content)?

Know the coupled model projections (CMIP5, CMIP6 and CORDEX), the relevant information from the IPCC report, and the limitations of the model projections.

2. Student

Task

The teacher mentees do the Arctic activity individually or in small groups. After that, list the key concepts underlying the scientific report and related to data usage and elaboration. Identify which difficulties the student can encounter in doing this activity and which contexts are used.

Guiding questions and examples of possible answers

What are the core ideas/big ideas/key concepts and models of the topic?

Fundamental measurements for describing the climate (temperature, precipitation and sea ice concentration). Scenarios. Feedback. Anthropogenic Greenhouse gases (CO2). Spatial-temporal scales and climate model projections.

What are the epistemic competences this activity can develop?

Competences in interpreting data and in constructing graphs and tables.

In which contexts are the activity's key concepts/scientific content embedded?

Arctic region: environmental issue (sea ice loss, impacts on different species of animals);

Global level: human impact.

What are the students' difficulties with the topic/activity?

Difficulties with different representations of data. Difficulties in choosing the right pathway to get the data or information using Atlas.

3. Analyst

<u>Task</u>

The mentees, working eventually in small groups, are invited to analyse the activity from an educational point of view. Firstly, identify the student's learning outcomes and list them. Secondly, identify the sustainability competences that can be developed, the methods to build, and the tools to assess them.

<u>Guiding questions and examples of possible answers</u>

Why is it important (meaningful and relevant) for students to learn this topic?

<u>Students' learning outcomes (educational value)</u>: Reading and interpreting data. Working with the average value. Reading and building graphs. Build tables (changing of representations: tables to graph and vice-versa). Understand a scientific text; Express numbers and information in a scientific report. Link the local changes to the global emissions; Acknowledge the human role in CC.

What (sustainability) competences does the analysed activity aim to develop?

Value and attitude
<u>Promoting nature</u>:
(K1) Knows about the main parts of the natural environment and that living organisms and non-living components are closely linked and depend on each other. (K) Knows that humans shape ecosystems and that human activities can rapidly and irreversibly damage ecosystems. (S) Can assess own impact on nature and consider the protection of nature an essential task for every individual. (A) Cares about a harmonious relationship existing between nature and humans.

Scientific inquiry

<u>Systems thinking</u>: *(K) Knows that every human action has environmental, social, cultural and economic impacts. (K) Knows that human action influences outcomes across time and space, leading to positive, neutral or negative results. (S) Can assess interactions between environmental, economic, social and cultural aspects of sustainability action, events and crises. (S) Can identify in a system those challenges and opportunities that have the greatest potential to trigger change for sustainability. (A) Has a holistic grasp of connections and interactions between natural events and human actions. (A) Acknowledge the root causes of unsustainability for which humans are responsible, such as Climate Change.*

CC scientific orientation: *Orientation to seek scientific information, critical information literacy, curiosity as a learner, future thinking, innovative attitude*

Creativity

Future literacy: *(K) Knows that effects caused by humans play a major role when mapping alternative and preferred future scenarios. (S) Can analyse and evaluate futures and their opportunities, limitations and risks. (A) Has a long-term perspective when planning, assessing and evaluating sustainability action.*

[*The sustainability competences in terms of knowledge, skills and attitude are described in the GreenComp (Bianchi et al., 2022) and the ClimComp*]

How are these competences developed?

Reflection, dialogue, discussion;
Learning in small groups, explaining to others, discussing with others;
Envisioning.

How can they be assessed?

Summative assessment with a similar activity.

4. Designer

Task

Individually, the teacher adapts the analysed activity according to their classroom needs, thinking about its implementation (accountability, knowledge distribution, discourse pattern, degree of input, degree of directiveness). After that, the teacher is invited to design a new activity.

Guiding questions and examples of possible answers

Whi are the sources of knowledge?

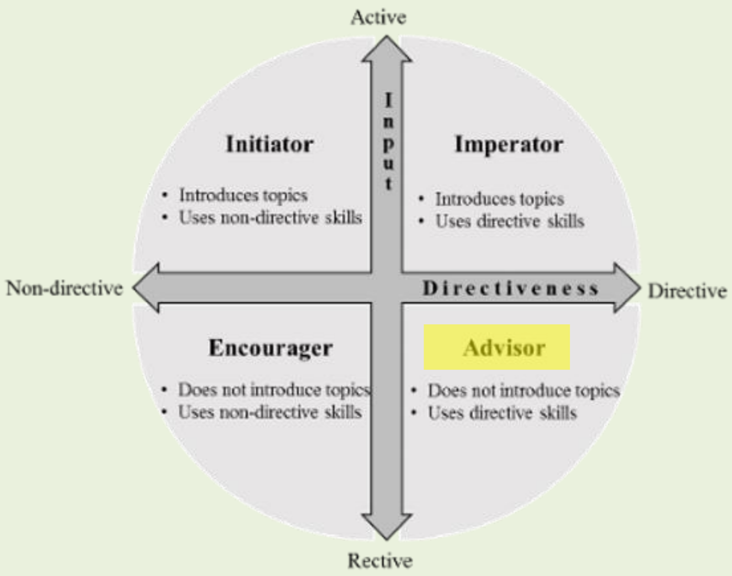
The text (scientific report) and the Atlas platform

Which participant structure will you use to enact this activity?

Mentor or partner

Which degree of directiveness and input will you use in the classroom?

The activity can require directive skills to help students to work with data. However, the mentor does need to introduce topics. (Advisor)



4.5.5 Complementary activity – hyperlinks

The Arctic activity presented does not develop all groups of CLIMADEMY competences. However, complementary activities can be designed to address other competences. Precisely, in the Arctic activity, different scenarios are used in order to get projections of temperature, precipitation, CO_2 emission and sea ice concentration. The key concept of the scenario can be used to design a complementary activity to foster other competences. The concept of scenario is situated in future studies. In complex systems at bigger space-time scales, such as for climate models, the concepts of projections become necessary. Uncertainty in projections implies moving from the idea of "one future" to the idea of the multiplicity of futures: Futures become a set of possible scenarios, where a scenario is a coherent, internally consistent and plausible description of a possible future state of the word (Levrini et al., 2019, 2021). The different visions of the future are possible futures (what the future could be), desirable futures (what the future should be) and probable futures (what the future will likely be). To visually represent this distinction it is possible to refer to the futures cone (Figure 24).

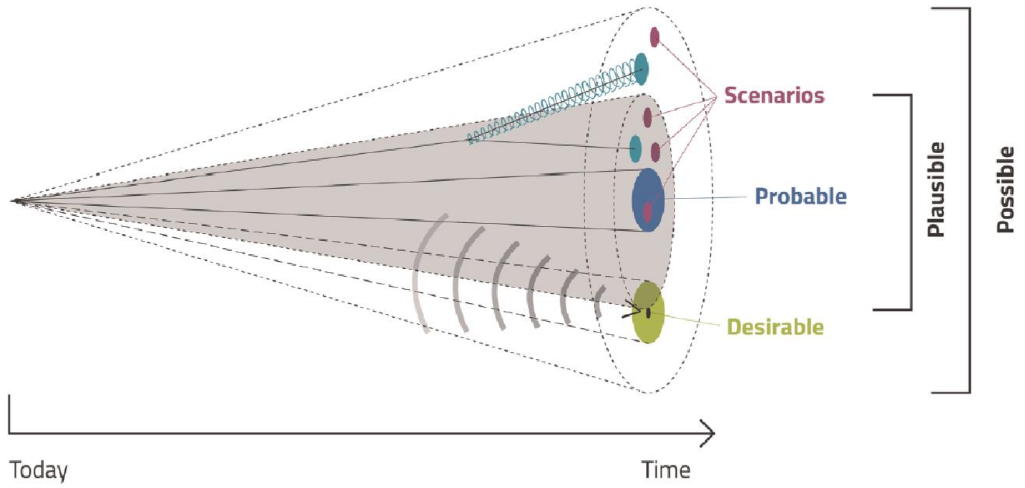


Figure 24. The futures cone

From the Arctic activity, the students can conclude that a desirable future corresponds to scenario SSP1-2.6 or better to scenario SSP1-1.9. In this case, it is not necessary to build the scenarios. However, it is possible to fix the desirable scenarios and design a back-casting activity to identify which action can be taken (individually or collectively, locally or globally) to achieve these desirable scenarios. It is worth noting that to identify the desirable scenarios, students should look at the impacts of CC, for instance, the consequences of having a sea ice-free in the Arctic region. While achieving the desirable scenario, the key point is the reduction of anthropogenic CO_2. Precisely, CO_2 emissions decline to net zero around or after 2050, followed by varying levels of net negative CO_2 emissions around 2050 and 2070, respectively, for the scenarios SSP1-1.9 and SSP1-2.6. The limitation of this activity is that the IPCC scenarios are much more complex and rich, and they are not described by only the CO_2 emission. However, these two scenarios can be described, after all, as low-emission scenarios with respect to the others, according to the IPCC report. For this reason, the students are invited to fix the reduction of anthropogenic CO_2 emission as a target in order to do this simplified task about the desirable future.

The desirable future scenarios are built on foresight and anticipation techniques. Foresight starts from the future and races it to the present through back-casting activities to design possible actions that can realise a desirable scenario (Levrini et al., 2021). These engage people at the emotional and, more generally, affective levels (values, beliefs, and attitudes). Furthermore, the ability of foresight and back-casting is linked to the action competences, which precisely implies the development of agency (the capacity to take responsibility for global challenges, take part in decisions, and consciously influence events and circumstances to realise the desired future scenario).

To set the action competences as the target, the activity designed for the students is the following: each group of students has to plan an action that they may undertake (as singles or as a group) in the present in order to favour the realisation of the desired scenario. They are asked to describe who they are and the position they hold when realising the action (for instance: political decision-maker, private citizen, an association, society, company or firm, a bank and the headmaster of a school), what they intend to do and why they think this action favours the realisation of the desirable scenario (Barelli, 2017). In Appendix 4.2, the worksheet for this complementary activity was presented. During this complementary activity, students learn that approaching CC implies a change in the ways we live in everyday life and we, collectively, make decisions; students get acquainted with the basic concept of back-casting coming from future studies; students take the agency to plan an action to make the desirable possible (action competences).

Conclusion

I had the opportunity to work with researchers of Science Education and teachers during this work thesis. My ambition was to connect these two "worlds" to avoid the risk of having teacher education that teachers feel distant and not useful for classroom daily work. The pedagogical model that we built can contribute to establishing this connection.

The first achievement of this work thesis has been identifying the teachers' needs in teaching CC and interpreting their nature and robustness in light of research literature (RQ1 and RQ2). A comprehensive picture of teachers' needs' has been depicted by collecting data from three different contexts. The final picture of teachers' needs reported in Chapter Two shows that teachers' needs are articulated in four different levels (Fundamental, practical, student and institutional level). Their analysis allowed us to recognise that CC touches very core aspects of teaching and represents real challenges both for the teachers and for the stakeholders (researchers included) that wish to address such needs. These challenges are demanding since they require perspective changes toward:

1. Teachers' professional identity;
2. The nature of educational resources;
3. The scope of Science Education;
4. The school culture and organisation.

These challenges and teachers' needs have been taken into account in the design of the pedagogical model for teacher education (RQ3). The elaboration of the model is part of the WP3 of the CLIMADEMY project.

My contribution to the designing and implementing process regarded all the phases of the work. A draft pedagogical model was built by the WP3 team and used as the starting point for the next steps. After this preliminary phase, I contributed to identify and elaborate on the theoretical frameworks so as to check that most of (if not all) the relevant aspects and goals of teacher education on CC were covered.

The second contribution was to extract the key messages, defined as the pedagogical messages that are approachable and relevant for the teachers to convey in teacher education. This was a challenging task since the theoretical frameworks used for the draft pedagogical model were developed in different research contexts and with different goals. Furthermore, in order to discuss the pedagogical model with co-designer teachers in the CLIMADEMY hubs, we designed an activity in which the theoretical frameworks, the key messages and suitable prompting questions were presented. The model stimulated a very interesting discussion in the Italian workshop, and the activity confirmed the relevance of the effort of transforming the research results into pedagogical messages.

The third contribution regarded the transformation of the pedagogical model into a “practical tool” to orient the design and the analysis of teaching activities. For this purpose, I designed a template to discuss, present or analyse an activity for teacher education according to the pedagogical model. I used the four phases of the STE-PE model to structure the template into four parts. For each phase, the role of the teacher mentor, as well as the role and the learning outcomes of the teacher mentees, are delineated. By answering the guiding questions selected for each part, the teacher conducts the educational reconstruction process, the identification of CLIMADEMY competences and the educational value of the activity under investigation, and finally, they are invited to position themselves with respect to the classroom and to design a new activity.

The final contribution of my thesis work was to illustrate how to use the template to analyse or design two different educational resources on CC for teacher training. The first resource refers to an activity already designed for students by Giulia Tasquier and Eleonora Barelli, that I adapted to teacher education according to the pedagogical model. This case showed that the pedagogical model could capture the pedagogical value of an activity initially built for other contexts and enrich it for teacher education, describing how to position respect the content knowledge, the sustainability competences, the class dynamics and other teachers. The second resource regards a new activity that I built from scratch specifically for teacher education. The pedagogical model worked for me as a compass in designing this activity, providing it with a specific pedagogical identity.

As final considerations of my work, I wish to sum up how the pedagogical model can represent a first way to encounter teachers' needs.

The first need regards the request of resources. These needs can have several meanings: it can be the request of a minimum syllabus, the request of “ready made solutions”, the request of orientation to search for, elaborate on and use educational resources. The first meaning is political, and several European projects, including CLIMADEMY, are debating on the core concepts. WP2 of CLIMADEMY is elaborating on this. The second one has been clearly recognised by the co-designer teachers as an attitude that especially for topics like CC teaching cannot be adopted. For this reason, the model insisted on the Model of Education Reconstruction (MER). It assumes “complexity” as a basic perspective and that there are not simple teaching receipts to deal with wicked problems, such as CC. For these reasons, we expect that guiding the teachers to appropriate the main messages of MER and orient them also to problematise the type of resources that can be designed and the kind of “answers” that they can find in them.

Furthermore, the participant structure framework and the different class dynamics can help teachers to position differently with respect to knowledge. CC is an intrinsically interdisciplinary topic and teachers have to accept that their expertise is necessarily partial, and this requires the exploration of new relationships with the other teachers or other sources of information. Positioning the teachers differently with respect to knowledge can contribute to changing the teacher's professional identity as the possessor of all knowledge.

Co-teaching and a redefinition of teachers’ relations touch the core of the culture and school organisation. Even if the pedagogical model can help in reconsidering the teaching of CC in school, for instance, considering the co-teaching context to optimise the time and involve teachers with different expertise, there are institutional constraints that remain unapproachable by the teachers even if they have been trained through the teacher education on CC described in this thesis. The work has unveiled this delicate point and contributed to recognise where and how the different roles can be seen.

Moreover, the CLIMADEMY competences framework can help teachers to position differently with respect to science education, namely changing the scope of science education in society in order to move from Vision I to a richer view that also incorporates Vision II and III.

From a more practical level, the CLIMADEMY model for teacher education is meant to embrace and deal with all the needs of teachers by inviting them to play different roles. (explorer, student, analyst and designer) during their training (STE-PE model) and by experiencing different degrees of directiveness and input with respect to knowledge management (MERID). Teachers' knowledge about epistemology and management of disciplinary core, interdisciplinary and social aspects on the one hand and suitable adapted or designed educational resources on the other are necessary to reach the learning outcome of sustainability competences in the classroom.

Future and relevant steps for the pedagogical model will be to implement it in teacher education, verifying its potential in responding to the teacher needs and valuing its impact on teacher education and consequently in teaching CC in schools.

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Sitography

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CLIMADEMY project website: https://climademy.eu/

[*Climate Change Teachers' Academy*. *Erasmus 2027 programme.* Agency: EACEA. *Call: ERASMUS-EDU-2021-PEX-TEACH-ACA. Project ID: 101056066*]

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IDENTITIES project website: https://identitiesproject.eu/it/

[*Erasmus+ Programme. Grant Agreement n°2019-1- IT02-KA203- 063184]*

IPCC Atlas platform: https://interactive-atlas.ipcc.ch/

I SEE project website https://iseeproject.eu/

[*Erasmus+ Programme. Grant Agreement n°2016-1- IT02-KA201- 024373]*

Appendix

A.1 Data set of the study about teachers' needs

A.1.1 Summary of group reports about teachers' needs (Italian workshop, part I, 8th May)

Prompt question: *"What are the teachers' needs?"*

Group 1 report

1) Problem related to the contents: "*We miss a lot of information*".
2) New pedagogical methods to consider coherently multi-disciplinary competences.
3) Provide examples of activities to do in the classroom. The teachers can adapt the activities according to their context. Have a structure, according to an educative model, to be filled by teachers.

Group 2 report

1) Specific knowledge related to the disciplines of Climate Change. For example, atmospheric stratigraphy or less known variable than carbon dioxide. Be informed about topical issues, for example, nuclear and green energy, electric cars and waste reuse.
2) Study the historical political decisions on climate and their consequences;
3) New pedagogical methods suitable for teaching CC. For example, role games, debate and circle time as pedagogical strategies.
4) Difficulties in teaching CC without being influenced by one's own opinion.

A.1.2 Transcription of teachers' discussion stimulated by some schemes about class dynamics (Italian workshop, part II, 8th May)

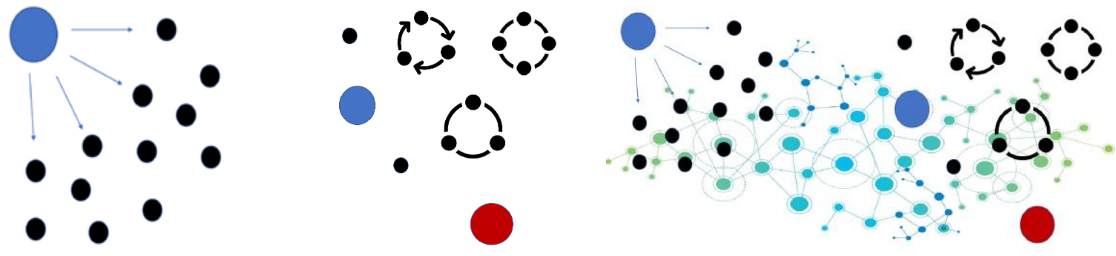


Figure A.1 Classroom dynamics schemes

Facilitator: "Which are the general feeling? What aspects do you consider more innovative (about the schemes presented)?"

Teacher 1: "For me, a tricky part is about self-conscience as a teacher. When students ask something that I'm not familiar with, I feel like: 'Maybe I should know these things!'. I try to do my best."

Teacher 2: "In picture one, arrows have directions. In this class dynamics, this means that, the teacher is keeping all the knowledge, and the student has just to receive the knowledge. In the complex images (picture two and there), there are no directions. The teachers can also learn something. Students can activate you (the teacher) in learning something. In this sense, this kind of class dynamics I think It's more comfortable for teachers. Of course with different expertise, but I (teacher) can learn with you (students)'. Teacher-students together to cope with a problem."

Research 1: (referring to the SRP scheme illustrated before): "Role of expert doesn't appear in the (SRP) scheme. The teacher cannot feel like an expert. But the teacher has not need to become an expert in CC. It probably doesn't exist an expert in the CC. There are experts in chemistry and the first thing they say in seminars are: '*I'm not an expert in CC*'. You don't need to become an expert to teach CC."

Research 2: "In that situation could be a value to normalize the fact that teachers have not all the answers. When students ask about something, we should explore together with students."

Teacher 3: “About the complex network in the class dynamics (picture three). I think It’s about a change in the self-perception. This is the main challenge. Only by starting from this (self-perception) that we can have an impact on the rest. This is very challenging."

Facilitator: “Yes, this is very challenging. It involves the identity of the teacher with respect to society, the knowledge, the colleagues and the problem.”

Teacher 4: (Referring to picture two) “The red dot is the teacher that doesn’t want to change. Some teachers don’t want co-teaching and abandon their role of power on knowledge.”

Research 3: “Can I add something? It’s possible to train teachers and students to learn to be engaged in solving a problem in which you are not an expert. In this perspective, it’s ok that teachers don’t know the answers”.

Facilitator: “But that’s difficult to accept.”

Teacher 1: “For me, it’s a work on myself. We are doing something about digital identity now. They ask me something that I don’t know! For me, it’s very difficult.”

Research 3: “It’s possible that maybe you know more than them in how to be critical in the answers and how to search for these answers. These are things in which you are more expert than them.”

Teacher 1: “But in other things, when they construct the questions for the colleagues by themselves, and so they make important questions. Like for examples about the filters on the social network, their meaning and perception. For the answers, they propose some interpretations. I cannot answer in any way. I can say: ‘*It could be*’, but who knows? I’m not a social teacher. I don’t teach social staff. ”

Facilitator: “I think we need to change the kind of input and reaction to this kind of question. The feeling that we have, as teachers, mainly as Italian teachers, we think that in front of a question, we have to answer in terms of knowledge, content and information.

Instead, in the other culture, the answer is to re-position with respect to the problem or try to find a way to search for the answer."

Research: "It's like: *'What are you going to do to find the answer?'*. It's ok, you don't know. But: *'What kind of search will you do?'* and *'Can we learn together?'*"

Teacher 1: "We were looking together about that. But it's not easy."

Facilitator: "Of course, it's not easy! Because it is really a change of perspective. When we are not the source of knowledge, we have the role of adults that can have some criteria to navigate the word in order to search for the answer. Even if the professional identity as a teacher can become questionable for some people."

Teacher 3: "Everyone should perceive themselves in this way. Not only the teachers."

Confusing voices (two or more people): "Everyone!"

Facilitator: "Teachers in society are one of the most delicate jobs, just because this (not have the answers) question their professional identity. This touches their professional identity as the expert on something. I mean, other people are much more free to play other roles. This is also why, I think, teachers should be the driver of change, to change how to positing all of us with respect the knowledge."

Teacher 3: " It is a culture shift."

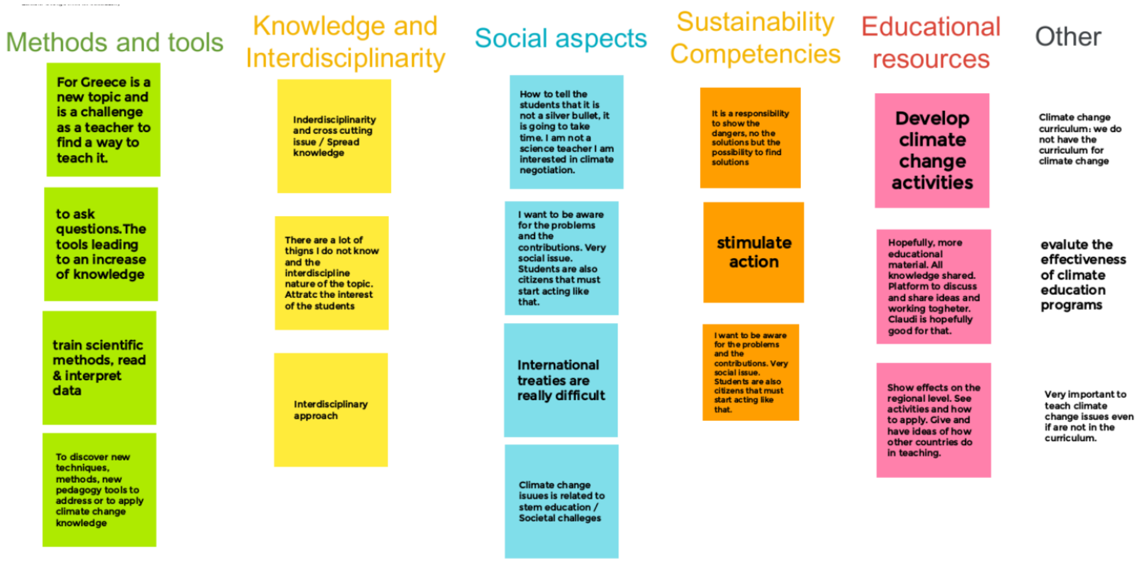
The discussion continued and ended with a digression on artificial intelligence as a source of knowledge in future scenarios.

A.1.3. In-service teachers' answers (International workshop, 8th May)

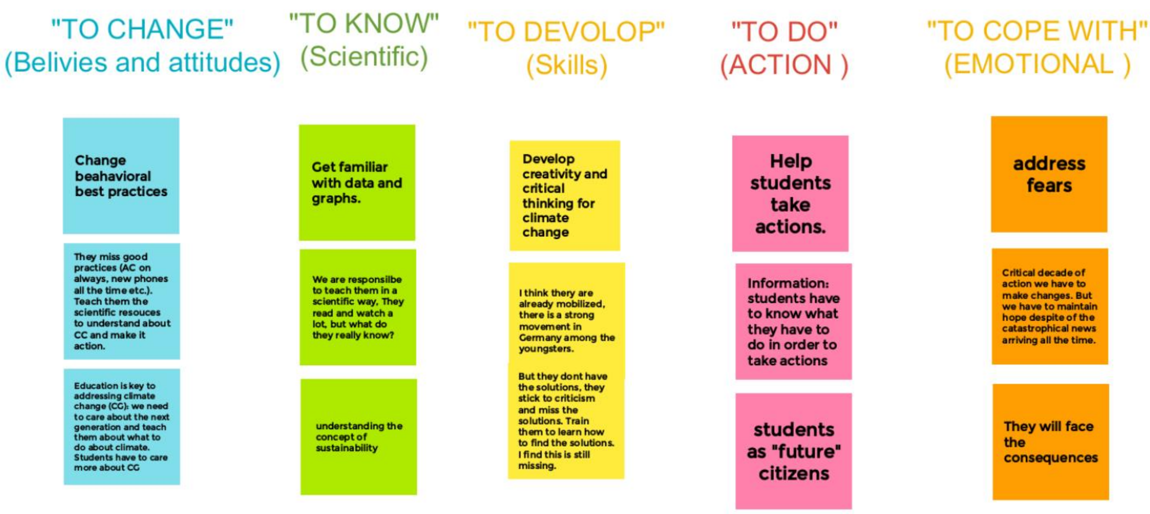
Prompt question: "Why is important to address climate change issue"

1) At personal level

2) At teacher/professional level



3) At student level



A.1.4. Transcript Group Three discussion (International workshop, 9th May)

Facilitator partner: *"Why do you think it is important to address CC at a personal level?"*

German teacher: *"Rivers are losing the water (the rivers are just empty). There are a lot of changes that take place pretty fast. It's against nature"*

Greek teacher: *"We are all citizens of the same planet. A few years ago we were thinking that CC will have to happen many many years in the future. But it is actually happening now. We are seeing all the consequences of climate change. It's important for us as citizens to know: what can we do? How can we react? It's very important to be informed and be educated in such an important issue."*

Finnish teacher: *"I agree with K*** (Greek teacher) about 'we are all citizens of the same planet'. In Finland, we don't see what is happening with CC as in another part of the world. We should be aware of Climate Change on a global level. Raising the empathy of the students."*

Facilitator partner: *"Why do you think it is important to address CC as a teacher?" Let's follow the same order to share.*

German teacher: *"It is my responsibility to show the others what the dangers are and to show them, not necessary solutions because I don't have the solutions, but possibilities to get solutions. I'd say It's my responsibility to deal with it and show what the future brings us."*

Greek teacher: *"Actually, for Greece (CC) is a new topic. It is challenging for me as a teacher: How to find a way to teach it. Actually, it is challenging for me as well because there are a lot of things that I don't know…I haven't studied them. It's a cross-curriculum topic: I have to incorporate chemistry, physics, and socio-scientific issue maybe. For me, as a teacher is challenging. It's something new. I hope I will manage to make my student be interested in this new topic."*

Finnish teacher: *"As a teacher: how to tell the student and make them realise that cure climate will be not fast as a process. We don't have a silver bullet to cure Climate. It's going* *to take time. I'm not a science teacher at all. So I'm interested in Climate negotiations, like how countries pretend to agree to mitigate CC and then nothing happens. At the professional level makes students release how negotiations at the international level are quite difficult"*

Partner two (researcher): *"K*(Greek teacher) said 'It is a new topic: I don't have the knowledge, I don't know how to do'. This proves that our work providing tools like the CALUDI platform can offer teachers knowledge. And teachers can ask for something like 'We need something more' or 'How can I teach this?". For example, can you give us as research or group of a country how can I teach this? The purpose of this project, it's to find teachers and help them. The kids live in a very fast world, but as A** (Finnish teacher) said there is no silver bullet to address Climate Change issues".*

Facilitator partner: *"Why is important to address Climate change issues with respect to the needs of your students" let me point out in that way. They live in a very fast word, why should they care? Why should the students be mobilized? How?*

German teacher: "*The German students are already mobilized, quite often here organize Fridays for future among the youngest. Most of actions are discuss with this politicians, protest and manifest in the street. They organize themselves, they get organized pretty fast. You said that CC will take some time. I think young people have enough energy, potential and maybe even ideas to make it turn back fast. I think they can do it, faster than we think.*

Facilitator partner*: "If they (students) are already mobilized, why should you emphasise in your curriculum climate change? Why should you spend time on CC?*

German teacher: "*Because they don't have the solutions, they just criticize. In German there is the critic, everything is wrong. They don't come to themselves with a solution. We can make them find solutions. We can train them and give input as teachers to look for solutions. This I find is still missing. I asked children regularly, 'What have you done against climate change and they said, 'Well, I went to protest against ***'…and then I asked, 'Have you ever planted a tree?" or something; nobody did that"*

Greek teacher: *"Actually, I think that we are responsible to teach them in a scientific way. They read a lot of things on Internet or watch a lot of things on TV. But what do they really know about CC? What are the consequences? And what can they do? For instance, they* *leave the class and the light is always on; they buy a new smartphone every year. But they don't realise that all this contributes to what we call "climate change". It's an opportunity to discuss social-scientific issues. And to teach them how to find scientific resources: Where can they find scientific information? How can they read it? How can they make action? My role is to alter the way they think and the way they are acting."*

Finnish teacher: "We have to make changes, make a more resilient society. We also have to maintain hope among the students, despite all the catastrophic news that we get from time to time. There have still be hope in order to continue to try mitigating CC for students. Otherwise, what is the point?"

A.2 Teacher ideas on activities about CC for teacher education

In the Italian workshop (8th May, Bologna), we asked the co-designer teacher the following question: "*What are the topics that involve CC? How can these topics be included in the school curriculum?*". The six co-designer teachers were equally split into two groups.

The main result of group one is that the CC topics can be well related to several disciplines. Despite the evident links of CC with geography, physics and chemistry, the co-designer teachers highlighted the links with no-scientific disciplines. Specifically, the importance of talking about the international organisation about CC, the possibility of talking about values and attitudes related to CC in civic education hours in Italian schools, the need to face the fake news about CC, and also the representation of data through modern art and the possible humanisation of the data. In this analysis, the teachers put themselves in their colleagues' shoes and think about how they can introduce the CC in their own disciplines. The interdisciplinarity aspect of CC activity strongly emerges from this group.

Group two think in a different way; they convey that a common point that can link most of the disciplines is the data, going from the collecting data activities to the representation and communication of the CC-related data. This is quite interesting because, in CLIMADEMY, we aim to design activities based on the data taken by the researcher stations. In addition, how the co-designer teachers argue it will be essential to focus in teacher education on what we can transfer to the pre-service and in-service teacher despite the topic and the disciplines, thinking about the competences that teachers with different backgrounds can develop about the data. In this analysis, the teachers search for a common point that can link almost all disciplines.

Following the co-designer teacher's suggestions, I focused my work thesis on two different activities. The first one is the biodiesel activity designed by Giulia Tasquier and Eleonora Barelli, in which interdisciplinary nature is evident, also involving social and economic aspects. The second one is an activity that I designed and aimed to use the data provided by the Atlas IPCC platform.

A.3 Educational resources to carry out the Biodiesel activity

A.3.1 Scientific text

[In the following is reported the biodiesel story (Barelli, 2017)]

Transport is one of the crucial themes as far as mitigation of climate changes are concerned, as it plays a central role in the domain of greenhouse gases emissions. The WG3 report of the fifth *Intergovernamental Panel on Climate Change* (IPCC, 2014) reported that 25% emissions are a result of the energetic sector, 24% to agriculture and stock-raising, 21% to industry, 14% to transports and 6.4% to the building sector. The remaining 9.6% are to be attributed to other energetic sources (data provided in 2010). In this paper, we shall carry on an analysis focused on the sector of transports and, more precisely, in that area concerning bio fuels and biodiesel.

Before tackling an analysis of the core problem, we find it necessary to provide general information about "biomasses". By considering the definition provided in the Directive of the EU Parliament and European Council (EC/2009/28/ Art. 2) the word "biomass" refers to the biodegradable part of products, waste and dissolved solids of biological origin as from agriculture (including vegetarian and animal substances), forestry and connected industrial work, and then also covering fishing and aquaculture plus the biodegradable part of industrial and urban waste. During combustion, biomass emits a quantity of CO_2 into the atmosphere equal to the quantity previously absorbed by plants while processing chlorophyll photosynthesis[4] and this is why the growing and combustion cycle of the biomass is defined as "zero energy balance"[5].

Biodiesel is obtained by squeezing and by transesterification[6] of oily biomass such as that from soy seed and rapeseed (canola). This is the bio fuel we intend to deal with, in this essay. As we already hinted at above, the use of this renewable source of energy is not necessarily favorable and it brings about consequences which may act at different levels. This is why the EU has commissioned extensive research aimed at understanding the variety of their impacts, while also quantifying their extent, in terms of both benefits and risks. Following here, a summary of considerations concerning the above mentioned research is provided for.

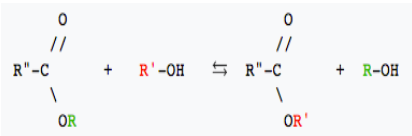
Using biodiesel for transportations, instead of gasoline, brings about a reduction of two well-known greenhouse gases emission, CO (50% reduction) and CO_2 (78,45%). The reason of the reduction can be found in the mechanism of production of the biomass itself: the carbon emitted during combustion is the one that already existed in the atmosphere, fixed by vegetables during their growth. The carbon is not, unlike the case with gasoline, the offset which has been sedimented under the earth's crust from time immemorial.

[4] The so called chlorophyll photosynthesis is a reaction which consists in the production of glucose and oxygen starting from the carbon dioxide in the atmosphere and from metabolic water, in the sunshine, as the following formula shows:

6CO2 + 6H2O + light -> C6H12O6 + 6O2

[5] Balance is actually a "zero balance" when we avoid taking into consideration any other contribution to the growing of the biomass: if, instead, we contemplate the fact that vegetable and arboreal imply the use of synthetic chemical fertilizers and phytochemicals, besides agricultural machineries, irrigation pumps and means for the transportation of the produce, it all means that a large quantity of fossil fueling is needed and it produces CO_2.That brings to the conclusion that there is no real balance as there is a clear-cut production of CO_2 because of the fossil fuels which are not renewable.

[6] Transesterification consists in the transformation of an ester into another ester by means of an alcohol. Here following, see the represented model: an ester with an alcohol in reported on the left, while, on the right, find another ester plus another alcohol:



Moreover, a 71% reduction of the emission of aromatic hydrocarbons is also documented; these compounds, that are naturally present both in oil and in carbon, are extremely toxic to the environment, human beings and animals as well as to flora and are numbered among the substances responsible for the ozone hole. Furthermore using biodiesel, sulfur dioxide (SO_2) emissions are almost totally eliminated. This gas, once entered the atmosphere, interacts with oxygen and water vapor and forms sulfuric acid[7]. This, on turn, comes back onto the earth in the form of acid rain which brings acidification of the ground and of water resources, so causing severe damage to the natural environment in many industrialized regions.

Very important is also the reduction (50%) in the emission of particulates. These are held responsible for severe diseases in man's respiratory and circulatory systems. This is why it has become indispensable to introduce anti-particulates filters to vehicles. As to the greenhouse effect, instead, an increased quantity of particulates contributes to the increasing of aerosol[8, that] helps the average of the global radiative forcing to decrease[9], partially compensating greenhouse effect.

[7] The chain of reactions that leads to the formation of acid rain is herewith reported and discussed. Sulphur dioxide in the atmosphere SO_2 is oxidized, so forming a reaction intermediate:

$$SO_2 + OH\cdot \rightarrow HOSO_2\cdot$$

As the intermediate is highly reactive exactly because of the unpaired electron (·), there immediately is one more reaction:

$$HOSO_2\cdot + O_2 \rightarrow HO_2\cdot + SO_3$$

In the presence of water, Sulphur trioxide SO_3 becomes rapidly converted into Sulphuric acid H_2SO_4:

$$SO_3 + H_2O \rightarrow H_2SO_4$$

[8] Atmospheric aerosol is composed by liquid or solid particles suspended in the air. It may form out of natural origins (ex: volcanoes) or anthropogenic (ex: emissions from industries and from transports) and can influence climate in multiple complex modes, because of its interaction with the radiation and with the clouds, either in terms of cooling or in terms of warming. Altogether, models and observations indicate that aerosol of anthropogenic origin has, on average, exerted an influence of cooling on the earth since pre- industrialization, the which has partially made up for that medium global warming due to the greenhouse gases, which would have occurred in case its influence were missing. The envisaged reduction of emissions of anthropogenic aerosol, undertaken by political acts aimed at making the quality of air healthier, could, in the future, "unmask" this warming (IPCC, 2014).

[9] Radiative forcing, W/m^2, is defined as the difference between solar radiation absorbed by the Earth and the reflected radiation: a positive radiative forcer brings greater radiation into the system and contributes to its warming, while a negative one involves a larger quantity of radiation coming out and so contributing to the cooling of the system. Radiative forcing is influenced by a compound of greenhouse gases, and this is why IPCC (2014) defined it as “the influence a given factor plays in altering the balance between in-going and out-coming energy of the system Earth-atmosphere and it indicates the importance of that factor as a potential modifier in the field of climate change”.

The use of biodiesel is also associated with the increasing emissions of nitric oxides (NO_X) to the discharge (10 - 15%), which are greenhouse gases. It is however important to stress that, by considering the whole production chain, the biodiesel supply chain emits about 20% nitric oxide less than the oil supply chain. A number of nitric oxides are then reduced, among which N_2O_3 (dinitrogen trioxide) and N_2O_5 (dinitrogen pentoxide) which are water-soluble. Because of atmospheric humidity they may form nitrous acid and nitric acid both found in acid rain.

In order to examine the problem in the view of a balance among the various impacts, it is not enough to restrict the field of the analysis to the emissions deriving from the use of bio fuel. An investigation of the consequences deriving from its production process is necessary.

Biodiesel is produced in countries different from those that make use and benefit of it, mainly in African Countries (Locke & Henley, 2013).

An example of effect of the production process is the following: the conversion of terrains destined to the growing of plantations into areas where biodiesel is produced implies an increase of the price of raw materials in the Third World (compared to high transport costs of food imported from other Countries), resulting in the increase of food insecurity[10] both from the point of view of availability and of access to food.

[10] In 1996, the *World Food Summit* defined food security as a situation when "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996). The 2009 *World Summit on Food Security* extended this definition, describing the four pillars of food security:

- availability: is the supply side of food security, determined by the level of production, stock levels and imports of food in the local area. Availability of foraged foods may also be important in certain contexts. Weather, yields, soil conditions, planting decisions, transport and storage infrastructure and a change in the trade regime can all affect availability;
- access: is the economic and physical access to available food, mainly from the household perspective. This can be from purchases, gifts or transfers of food. Households' economic access to food is determined by overall household income, disposable income for food and food prices. Ease of physical access to markets to acquire food is influenced by the proximity of markets and other food sources (fields, forests etc.) and the existence and quality of infrastructure;
- use: is the way individuals are able to consume food, which has a direct impact on nutritional status and is closely linked to feeding practices, preparation and distribution of food between household members;
- stability: is the maintenance of food security through time while an individual or household may temporarily be food-secure, outside shocks such as food price volatility, unemployment or harvest failures may undermine food security. Shifting demographics within a household, such as the birth or death of a child or other household member, may also affect the stability of food security over time.

Still considering the use of terrains, the spreading technique of monoculture for the production of biodiesel has implied a reduction in biodiversity and has enhanced the risk of growing species of insects and bacteria which strongly damage crops. As a consequence, it causes an increase of the price of the few raw materials left. An extensive use of monoculture also raises the risk of soil erosion and the progressively increase of its vulnerability; this contributes to the increase in food insecurity from the point of view of stability, because both local economics and populations come to face times of shortage in the production of crops. The increased vulnerability of agricultural lands caused by insects and parasites also involves a larger use of pesticides which contain nitrous oxide (N_2O), a greenhouse gas that adds to the ozone hole.

The introduction of biomass cultivations might however support the production of crops of owners of small lands and land administrators, who may sell and/or hire their own lands or reach to agreement with large companies: the companies provide technical knowledge about the production of biomass (fertilizers, agrochemical products, a variety of seeds), and/or adequate technological means and, in exchange, they owners or administrations guarantee the companies preferential treatment when buying raw material. This innovation may increase crops and, consequently, the availability of food products, thus conveniently contributing to improving food security[11], even if this would happen only to the involved social class, which means to a small section of the population.

Finally, the presence of cultivations for biodiesel, managed by large companies, may require to enhance the building of social facilities such as roads, electricity networks, paid by the company itself or by the government. This general improvement may, on turn, bring about advantages in traveling, so also favoring working and studying opportunities, as well as an easier way of reaching market places. This would also increase both economic and physical access for people to food stock.

[11] From Govareh J., Jayne T.S. & Nyoro J. (1999). *Smallholder Commercialization, Interlinked Markets and Food Crop Productivity: Cross-country Evidence in Eastern and Southern Africa.* Lansing, MI: Università del Michigan; cited in Locke & Henley.

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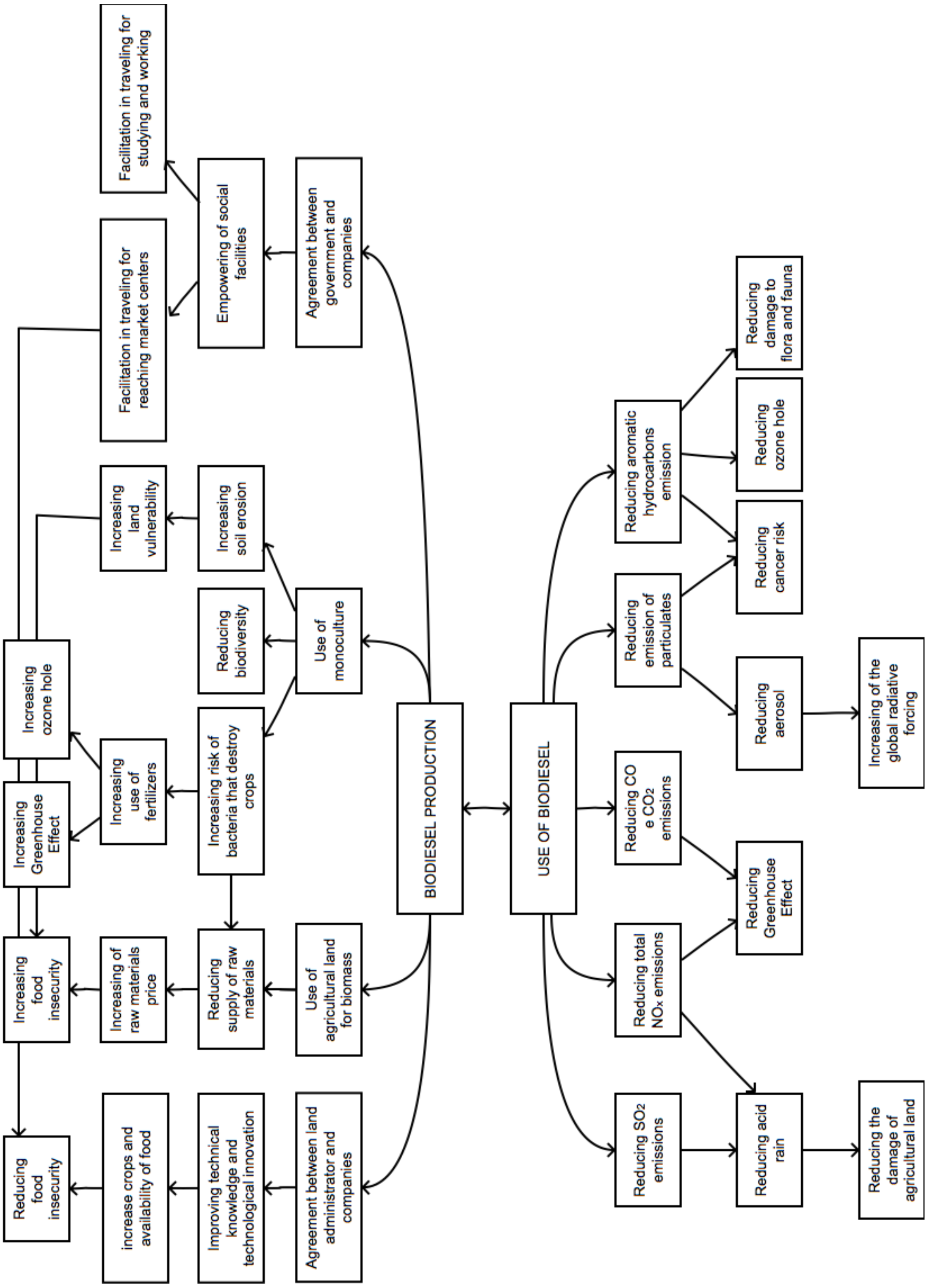
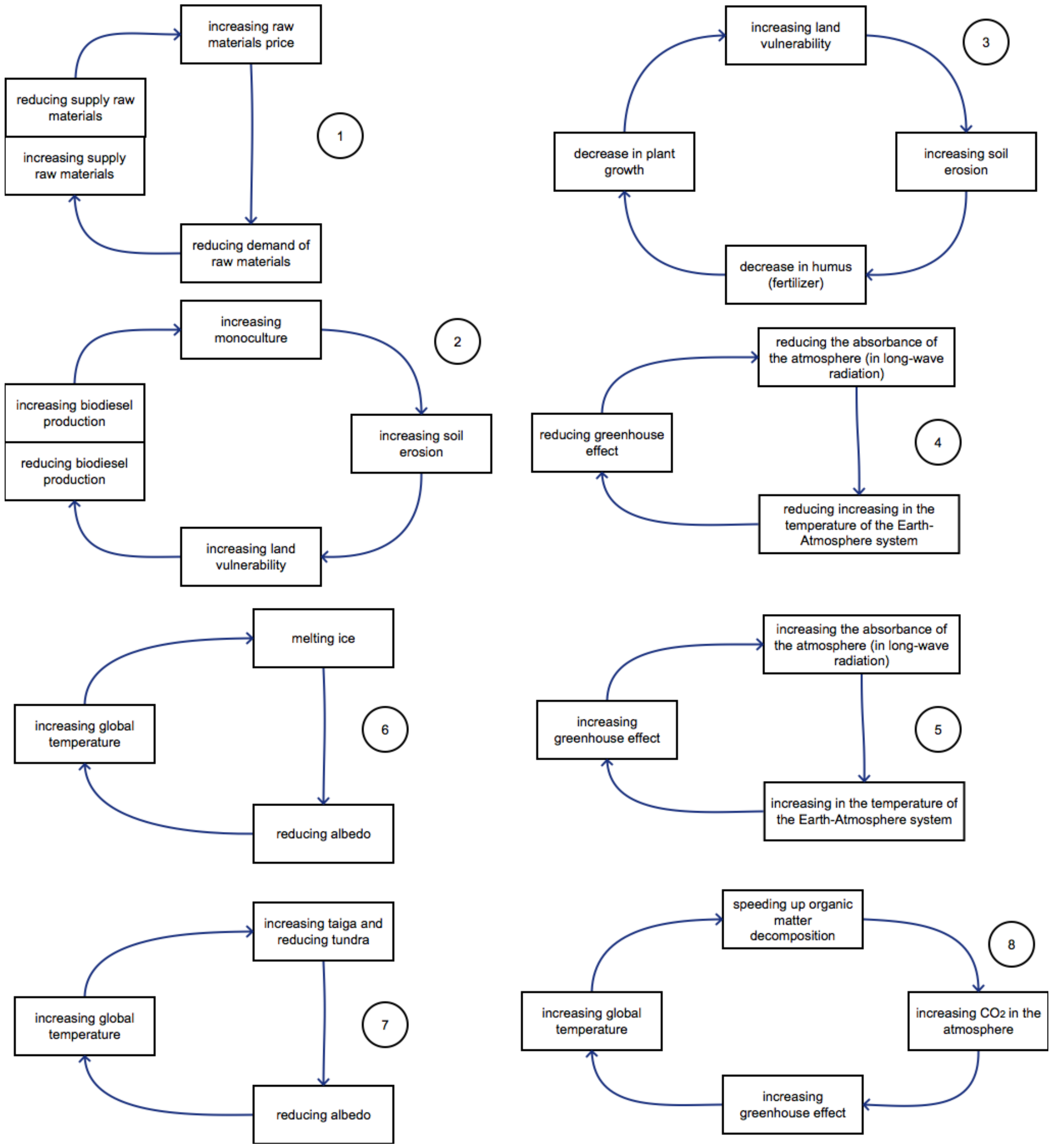
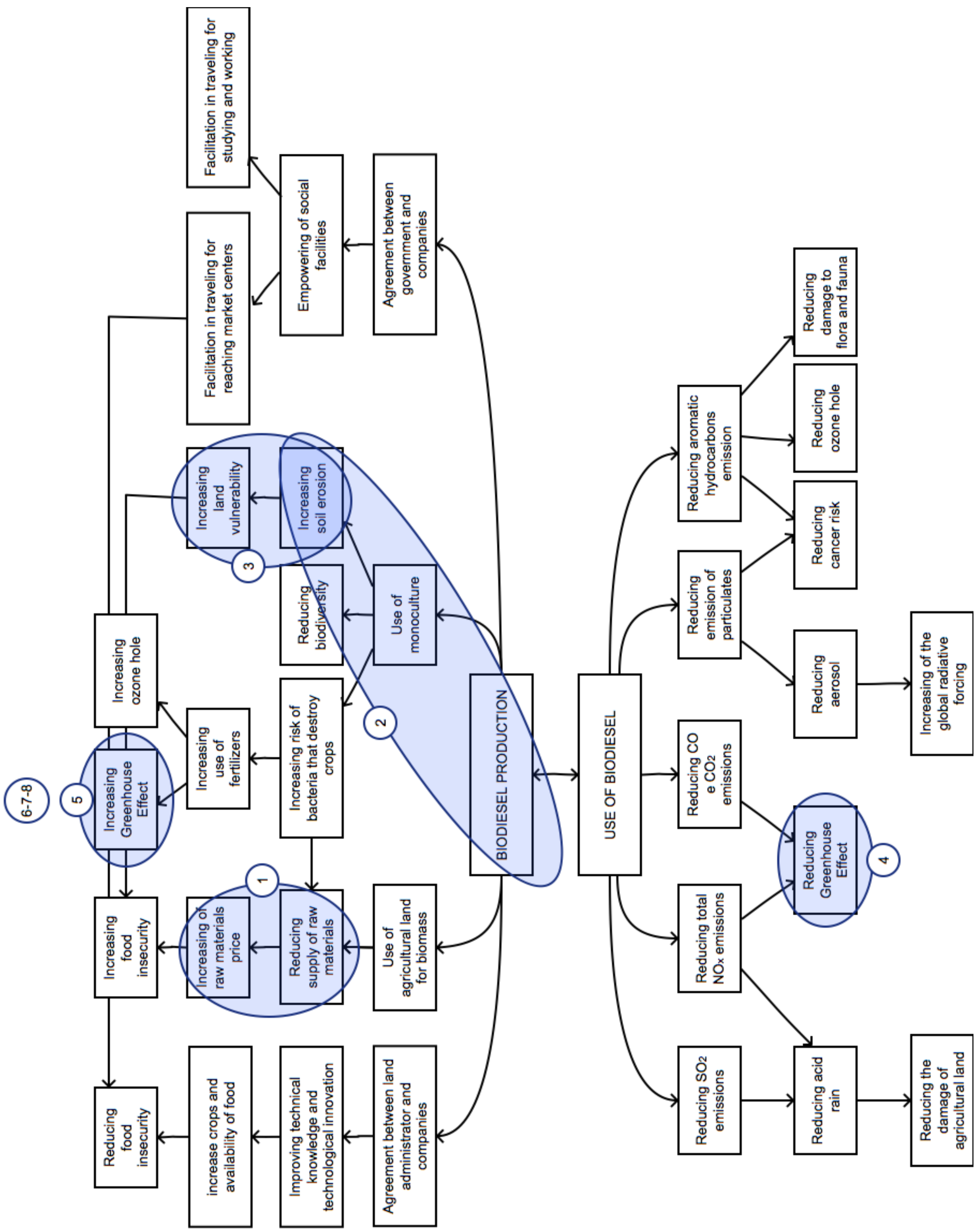
A.3.2 Causal effect map



A.3.3 Feedback loops



A.3.4 Cause-effect map with the feedback areas highlighted



A.4 Educational resources to carry out the Arctic activity

A.4.1 Scientific report on the Arctic region (in bold the answers according to the IPCC Sixth assessment report)

[*Students are supposed to fill the text with words or numbers and build graphs using the data provided by the Atlas platform. In the following, I report the scientific text and the solution, namely the missing words/numbers (in bold) and the completed graphs (Graph A and Graph B)]*

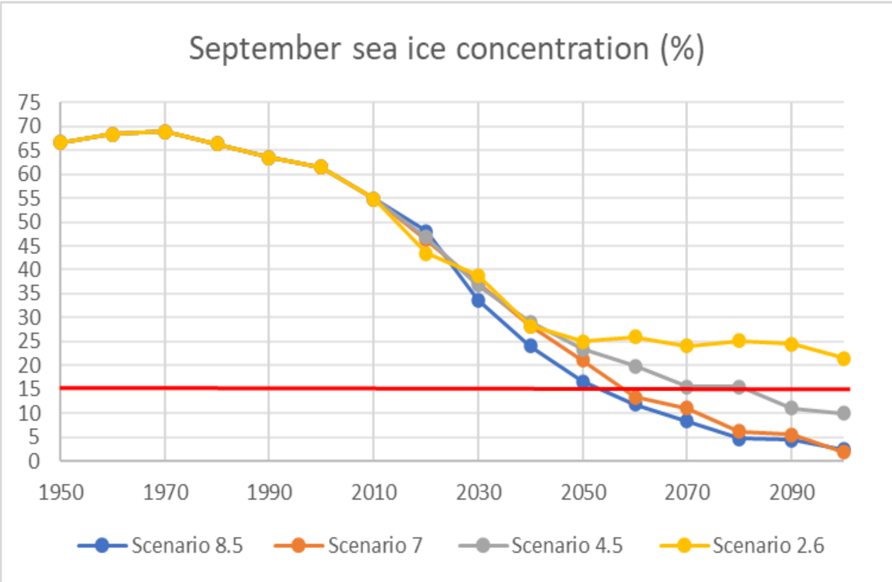
The Arctic region comprises the Arctic Ocean (ARO), Russian Arctic (RAR), Greenland and Iceland (GIC), and other surrounding land areas in Europe (NEU) and North America (NEN, NWN). The region is one of the coldest and driest regions on Earth and plays a key role in influencing global and regional climates and the hydrological cycle.

The Arctic has warmed at more than ______ (**twice**) the global rate over the past 50 years, with the ________ (**greatest**) warming during the cold season (October-May). This is based on various Arctic amplification processes, in particular the combined effect of several related feedback processes, including between various radiation components and (a) the albedo of sea ice and snow, (b) water vapour, and (c) clouds, as well as poleward energy transports. The sea ice albedo feedback (increased air temperature reduces sea ice cover, allowing more energy to be absorbed at the surface, fostering more melt) is a key driver of sea ice loss. Along with the amplified warming, the Arctic has become moister. AMAP (Arctic Monitoring and Assessment Programme) reported Arctic precipitation increases of _______ (**1.5–2.0%**) per decade, with the ________ (**strongest**) increase in the ______ (**cold)** season.

The projections assessed in the sixth assessment report of the IPCC are mainly based on the Shared Socio-economic Pathways (SSPs) used in the CMIP6 (Coupled Model Intercomparison Project Phase 6). The scenarios available on the Atlas platform are SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5. In the SSPx-y labels, the first number refers to the assumed shared socio-economic pathway, and the second refers to the approximate global effective radiative forcing in 2100. Based on these projections, it is very likely that the Arctic annual mean temperature and precipitation will continue to increase, reaching around ______ (**11.5°C** ± 3.4°C**)** and _______ **(49** ± 19%**)** over the 2081–2100 period (with respect to a 1995–2014 baseline) under the SSP5-8.5 scenario or ________ (**4.0°C** ± 2.5°C) and ___________ (**17** ± 11%) under the SSP1-2.6 scenario.

The observed decrease in Arctic sea ice area[10] is a key indicator of large-scale climate change. Sea ice extent[11] has declined since 1979 in each month of the year. Changes are largest in summer and smallest in winter, with the strongest trends in September. The sixth assessment report of the IPCC assessed that the Arctic is projected to be, on average, practically _______ **(ice-free)** in September near mind-century under _________________ (**intermediate and high)** greenhouse gas emissions scenarios, though not under ______________ (**low emissions)** scenarios, based on simulations from the latest generation Coupled Model Intercomparison Project Phase 6 (CMIP6) models. Specifically, it is likely that the Arctic Ocean in September, the mouth of the annual minimum sea ice area, will become practically ice-free (SIA< 1×10^6 km^2) average over 2081-2100 and all available simulations only under the __________________ **(SSP2-4.5, SSP3-7.0, and SSP5-8.5)** scenario. The following graph shows the September sea ice concentration up to 2100 for the Arctic Ocean under the four scenarios SSP1-2.4, SSP2-4.5, SSP3-7-0 and SSP5-8.5.

[Build a graph that shows the September sea ice concentration up to 2100 for the Arctic Ocean under the sea different scenarios]



Graph A: September sea ice concentration up to 2100 for the Arctic region under different scenarios

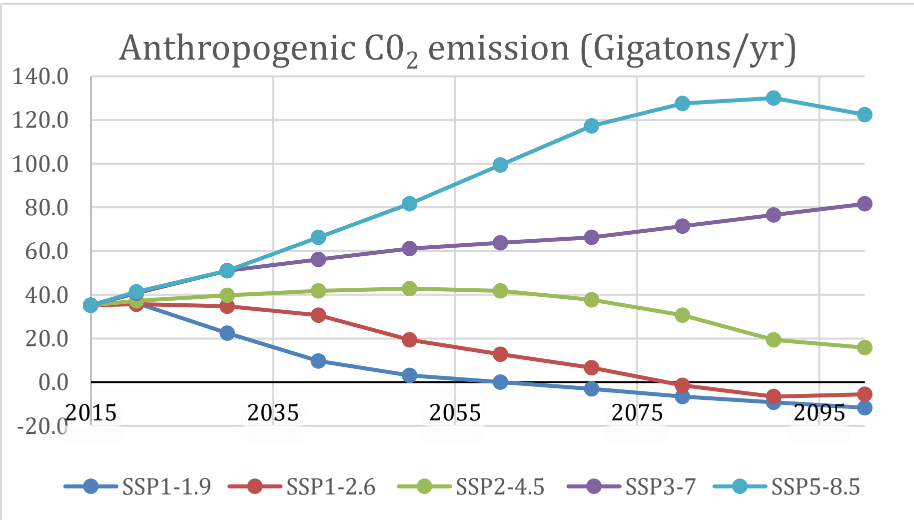
[10] Arctic sea ice area (SIA) is calculated based on measurement by passive satellite sensors that provide near-continuous measurements of gridded, pan-Arctic sea ice concentration from 1979 onwards.

[11] The sea ice extent (SIE) is the total area of all grid cells with at least 15% sea ice concentration (grid-dependent).

While based on CMIP6 simulations, it is very likely that the Arctic Ocean will remain sea ice-covered in winter in _____ **(all)** scenarios throughout this century. Loss of multi-year sea ice and the occurrence of a seasonally ice-free Arctic Ocean by the middle of this century will result in substantial range contraction[12], if not the disappearance of several Arctic fish, crab, bird and marine mammal species, including possible extinction of seals and polar bears in certain regions.

It is unequivocal that human influence has warmed the atmosphere, ocean and land. Observed increases in well-mixed greenhouse gas (GHG) concentrations since around 1750 are unequivocally caused by human activities. Human influence is very likely the main driver of the decrease in the Arctic sea ice area between 1976-1988 and 2010-2019 (decreases of about 40% in September and about 10% in March). The IPCC Report assesses the climate response to five illustrative scenarios that cover the range of possible future development of anthropogenic drivers of climate change found in the literature. They start in 2015 and include scenarios with high and very high GHG emissions (SSP3-7.0 and SSP5-8.5) and CO_2 emissions that roughly ________ **(double)** from current levels by 2100 and 2050, respectively, scenarios with intermediate GHG emissions (SSP2-4.5) and CO_2 emissions remaining ________ **(around)** current levels until the middle of the century, and scenarios with very low and low GHG emissions and CO2 emissions declining to net zero __________ (**around or after 2050)**, followed by varying levels of net negative CO2 emissions[13] (SSP1-1.9 and SSP1-2.6). The following graph shows annual anthropogenic emission trajectories (period 2015-2100) for carbon dioxide (CO2) in all scenarios (expressed in gigatons/year).

[Build a graph for all scenarios and the period 2015-2100]



Graph B: Annual anthropogenic emissions over the 2015-2100 period.

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[12] We define range contraction as the disappearance of a species from part of its past range (the area where a particular species can be found during its lifetime.

[13] Net negative CO2 emissions are reached when anthropogenic removals of CO2 exceed anthropogenic emissions (Glossary).

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A.4.2 Task and worksheet for the complementary activity

Task: *Your group and you plan an action which you may undertake (as singles and/or as a group) in the present, in order to favour the realization of your desired scenario. As you plan the action to undertake, describe: a) who you are and the position you hold when realizing the action (for ex.: political decision-maker, private citizen, an association, society, company or firm, a bank, the headmaster of a school, etc.), b) what you intend to do, c) why you think this action favours the realization of your desirable scenario.*

a) What we are
b) What we do
c) Why the action favours the realization of the scenario