frontiers | Frontiers in Education

ORIGINAL RESEARCH
published: 11 April 2022
doi: 10.3389/feduc.2022.689329

Scientific Literacies for Change Making: Equipping the Young to Tackle Current Societal Challenges

Giulia Tasquier[1]*, *Erik Knain*[2] *and Alfredo Jornet*[2]

[1] *Department of Physics and Astronomy "A. Righi", Alma Mater Studiorum – Universitá di Bologna, Bologna, Italy,*
[2] *Department of Teacher Education and School Research, University of Oslo, Oslo, Norway*

Dealing with the threatening challenges and profound changes that characterise our era requires the development of knowledge and skills to navigate the uncertainty and complexity of science as part of society and everyday life. How can we support school students in transforming the base of knowledge and experiences to face the ongoing crises and contribute as individuals, citizens, and active participants in a democratic society to enable the transformation that is called for? We address this broader question through a study framed within the Horizon 2020 project titled Science Education for Action and Engagement toward Sustainability (SEAS), aimed at promoting new forms of scientific literacy and skills to empower students to become agents of change. Most centrally, SEAS aims at incorporating a transformative dimension that is often lacking in current conceptions of scientific literacy. In SEAS, school and school science are conceived as involving learning and transformation across three spheres—the practical, the political, and the personal—where both individuals and their institutional contexts are subject to change as participants gain agency over their learning processes. In this study, we illustrate this approach and present the analysis of a first pilot iteration within the project's Italian Local Network, which shows the kind of individual/collective dynamic that the project's transformative activities afford.

Keywords: scientific literacy, societal challenges, climate change, transformation, secondary school students

Edited by:
Maria Evagorou,
University of Nicosia, Cyprus

Reviewed by:
Gultekin Cakmakci,
Hacettepe University, Turkey
Olia Tsivitanidou,
University of Nicosia, Cyprus

Correspondence:
Giulia Tasquier
giulia.tasquier2@unibo.it

Specialty section:
This article was submitted to STEM Education, a section of the journal Frontiers in Education

Received: *31 March 2021*
Accepted: *17 February 2022*
Published: *11 April 2022*

Citation:
Tasquier G, Knain E and Jornet A (2022) Scientific Literacies for Change Making: Equipping the Young to Tackle Current Societal Challenges. Front. Educ. 7:689329. doi: 10.3389/feduc.2022.689329

INTRODUCTION AND BACKGROUND

We face an increasingly worrying and overwhelming future. The global sustainability crisis is manifesting in many forms, including urgent environmental problems like climate change. Two days before the writing of these lines, the Intergovernmental Panel on Climate Change (IPCC) released its 6th assessment report about the available physical science on climate change (IPCC, 2021), presenting what the UN general secretary has referred to as a "code red for humanity" (McGrath, 2021). In addition, since early 2020, the COVID-19 pandemic has strongly affected societies across the globe and continues to impact our lives in different ways. For citizens in democratic societies to deal with these events and to meaningfully participate in urgent decision-making to address the rapid and profound changes that the current situation presents, an understanding of key scientific principles, practices, and ideas, as well as the development of skills to navigate the uncertainty and complexity of science as it intersects with everyday life, is required (Dillon and Avraamidou, 2020; Erduran, 2020; Levrini et al., 2020; Reiss, 2020).

The study of Schreiner et al. (2005) discusses reasons why climate change teaching and learning are difficult, especially when it comes to connecting knowledge and action. They point to the complexity of the issue, that there is a comparably long timescale that makes the physical phenomenon of climate change essentially "invisible" in everyday life, and easily perceived as "everybody's" problem, where individual contributions seem insignificant. In the context of modern societies, learning to become a citizen involves the consideration of scientific issues along with understanding the moral, socio-economic, and political problems and contexts of its application (Hodson, 2003). With the complexity of real-life challenges, scientific knowledge as traditionally taught in schools is not readily applicable but needs to be considered along with socio-political concerns and other sources of knowledge for it to become usable, both from a practical perspective (Jenkins, 1994) and with respect to becoming meaningful for the individual through culturally validated world views (Cobern and Aikenhead, 1998).

Students' perceptions of climate change are framed by broader emotional and socio-political and cultural contexts, concerns, and values, such as worldviews and views on science, perceptions of the ecosystem, of citizenship, and of risk assessment (Hoffman, 2015), and perceptions of the nature of the very problem of climate change (Hulme, 2015). Accordingly, as science educators, we are aware of the urgent need to further develop ways of understanding and teaching scientific literacy that consider the complexity of science as it entangles with everyday life and to develop pedagogical principles and practices that can be useful to prepare the young generations to manage today's and tomorrow's urgent sustainability challenges (European Union, 2015; Levrini et al., 2020, 2021). As we argue throughout this study, however, it is not enough to connect scientific issues to the relevance of everyday life; integrating an agency-oriented, politically aware, and transformative stance into science teaching and learning is crucial for successfully connecting action and learning (Bøe et al., 2011; Stetsenko, 2016a; Knain and Odegaard, 2018). Accordingly, in this study, we raise the question: *How can we support school students to critically engage with scientific knowledge and expertise, not only to foster decision-making but also to become agents of transformative change as current complex societal challenges require?*

In this study, we address this question by presenting an approach to science education that makes change-making and transformation its focus. We illustrate this approach with the design of a particular teaching module on climate change and the analysis of a first pilot study led by the Italian Local Network in the context of the Horizon 2020 project titled Science Education for Action and Engagement toward Sustainability (SEAS).[1] The analysis aims to show the kind of individual/collective dynamic that a set of particular activities and tools implemented within the climate change module as well as to document the kind of impact they had on transformative aspects.

From Deeper Understanding to Action and Engagement Toward Sustainability

Within the field of science education, the question of students' development of scientific literacy and citizenship skills has been discussed at length. Indeed, the importance of exploring and incorporating the societal dimension of science is widely investigated in research studies on the role of Socio-Scientific Issues (SSI) in science education (e.g., Kolstø, 2001; Levinson, 2007; Sadler et al., 2017; Tasquier and Pongiglione, 2017). A recent reflection on SSI research highlights both successful and limiting aspects of SSI (Evagorou and Nielsen, 2019). On the one hand, SSI represents an effective context for increasing students' motivation to learn science, especially if the topic is of personal interest, and the development of knowledge and processes contributes to scientific literacy, including evidence-based argumentation, consensus building, moral reasoning, and understanding and application of scientific content knowledge. On the other hand, discussing controversial issues requires advanced scientific knowledge and reasoning generally unfamiliar to students and may require students to improve the ability to solve complex problems by drawing on knowledge, values, skills, and attitudes that enable effective action. The first aspect that the existing research highlights are the importance of the role of teachers in leading classroom discussions to support the development of such knowledge and skills, though, as Tidemand and Nielsen (2017) assert, teachers often have difficulties in operationalising and assessing these complex competences. If educational contexts are not designed to explicitly support these types of socio-scientific inquiry skills, the complexity of SSIs may be reduced to compliance with fact-reproducing practices familiar to students and teachers alike (Byhring and Knain, 2016).

In the literature, there are interesting models dealing with the topic of climate change that aim at developing complex skills (e.g., Sadler et al., 2017; Levrini et al., 2021). For example, the conceptualisation of the SSI approach by Sadler et al. (2017) was thought to progressively encourage students to develop their own positions on SSI. In this model, students are guided to develop scientific knowledge as well as to consider social, political, economic, ethical, and moral aspects of the problem (Sadler, 2009). Empirical results have shown that models like these ones are effective contexts for the development of knowledge and processes contributing to scientific literacy, including evidence-based argumentation, consensus building, moral reasoning, and understanding and application of science content knowledge (Sadler, 2009; Echeverri and Sadler, 2011).

A central model for this study is the I SEE teaching/learning model approach to STEM education aims to incorporate *future thinking* as an aspect in the societal, vocational, and personal dimensions that make science relevant for students, emphasising the conceptual and epistemological value of future-thinking in education (Branchetti et al., 2018). This approach is characterised by the choice of *future-oriented* topics that not only include scientific contents and scientific practices (reasoning, arguing, explaining, etc.) but also are likely to be significant in the students' future. They may, for example, represent a societal challenge or prospect that is controversial because of its implications for future societies, the environment, or working life. These challenges are not likely to be solved in the near future because of their complexity and often involve rapidly evolving technologies with great expectations. The aim is to develop what is called *future-scaffolding skills* and to

[1] https://www.seas.uio.no

foster students' personal, societal and vocational agency and identity, and the primary outcomes strived for are competencies and the ability to put those competencies into action. Future scaffolding skills have been defined as those abilities to construct visions of the future that empower action in the present with an eye on the horizon (Levrini et al., 2021). In the I SEE approach, the development of such competence entails learning aims at three levels, corresponding to the types of activities presented above: conceptual and epistemological knowledge, future-scaffolding skills, and action competence (Branchetti et al., 2018).

The models discussed so far work in developing complex socio-scientific inquiry skills, the first mainly in terms of introducing ethical and moral dimensions, by exploiting the introduction of values into scientific discourse, as well as by acting at a level of building argumentations toward decision-making (Sadler et al., 2017). The second model focuses instead on developing future-scaffolding skills by exploiting the future dimension intrinsically embedded into scientific epistemology (Branchetti et al., 2018). However, in the current fast-changing context of crisis, an additional challenge concerns the quest for *making science a source and resource for deep change and transformation*, as well as making it more relevant to current real-world challenges. The recent emergence, all around the globe, of youth movements concerning climate change shows the great extent to which young people feel engaged with complex scientific issues that represent real threats to their present lives and futures. It is a matter of fact, put in front of our eyes by all the media, that, in 2018, disappointed with inaction by world leaders and adults more generally, young people started to express their frustration in the streets, creating a more empowering narrative about climate change and a sustainable vision for their future than would what have been possible without their voice and strength, a movement and force that paradoxically started outside school and school science classroom, precisely refusing to enter those classrooms (*via* school strikes) until responsive and responsible action is taken. Missing in most existing approaches is specific measures and tools to support actual engagement and action toward change, and a better understanding of an individual's potential and capacity to become an agent of change that understands her potential in a larger socio-political context. How do our approaches to educating for scientific literacy address the need for an education that feels not only relevant but also empowers learners to take a knowledge-based stance and act toward change?

Scientific Literacies for Change-Making: Integrating Change in Science Education

As the review of the literature above suggests, developing scientific literacies useful for twenty-first century learning contexts involves not just the acquisition and use of scientific knowledge but also developing skills of scientific inquiry and argumentation through and for transformational action in real contexts (Hodson, 2010). Young people represent a powerful source of transformation in society, and they should be educated to engage critically with complex societal challenges, such as climate change. However, current (science) education is far from having gathered that potential, partly because empowering young people to be systemic thinkers and change agents as well as to connect science to beliefs, values, and interest is not a straightforward task and requires explicit embedding both competence and means for change (Bentz and O'Brien, 2019). The notion of scientific literacy for change-making and transformative action implies that learning science involves not just developing intellectual or discursive/argumentative skills related to addressing SSI but also requires practical, personal, and political dimensions and *commitments* related to bringing science into the civic and real-life contexts (Roth and Jornet, 2014; Stetsenko, 2016a).

Missing from most approaches to science education today is an explicit consideration of what change is and what it entails, not just as a theoretical and discursive dimension but also as a personal and practical achievement that involves agency and that has consequences beyond the academic sphere of classroom learning. Within SEAS, we defined agency as "the ability to influence and exercise power" (Bengtsson et al., 2020). To integrate this understanding of change into science education, our own approach has involved drawing from literature on the sociology of climate change and climate action. In particular, we built upon the heuristic model of the three spheres of transformation developed by O'Brien and Sygna (2013), developed as a heuristic integrating diverse approaches to transformation in response to climate change and examining the changes necessary for individuals and organisations to meaningfully address climate change (O'Brien and Sygna, 2013). According to this model, transformation is a process that takes place across three closely related, interdependent spheres: (i) a *practical* sphere, which includes both technical and behavioural changes that contribute to the solution of climate change and sustainable issues; (ii) a *political* sphere, which highlights the systems and structures that facilitate or hinder transformation and which includes the social norms, rules, regulations, institutions and infrastructure that define how society is organised as well as the social and ecological systems and structures; and (iii) a *personal* sphere, which highlights the importance of individual and collective worldviews, values, beliefs, and paradigms that are at stake and which drive people's motives for practical and political action, shaping the ways that make possible both the enacting of behavioural and technical actions (i.e., practical sphere) and the shaping of systemic and structural layouts (i.e., the political sphere) (O'Brien and Sygna, 2013).

Though developed in the context of climate change research, the heuristic of three spheres of transformation is useful both as a means to examine our own science education practices as well as to inform how to develop pedagogical implementations that support scientific literacy for action and engagement, especially pointing to the integration of these three spheres as a condition for the facilitation of actual connection between knowledge and action. First, the heuristic allows us to consider the extent to which existing approaches to science education cut across the three interrelated and interdependent spheres. A quick read over the research reviewed above reveals that, just as is the case in the field of climate change action, most attention has historically been directed at either educating about technical solutions—by focusing on the provision and acquisition of relevant scientific and socio-scientific knowledge—or/and by focusing on discursive and argumentative dimensions to support diversity and management of plural worldviews on sustainability issues (Öhman, 2009). The political dimension, that is, of how actual structures and systems are connected to and mediate the other two spheres tends to be much less present in current literature (Hodson, 2017). The challenge remains how to integrate the three aspects and make them relevant to science education, thereby also empowering students through science education practices.

An additional source that informs our work with regards to how these insights on change can be enacted and implemented as pedagogical interventions comes from cultural-historical approaches to (science) education (Roth and Lee, 2007; Roth and Jornet, 2017), according to which knowing, agency, and acting are connected in and through concrete, material, tool-mediated practices. The latter insight brings in the need to integrate change-making not just as content, as a theoretical aspiration and value in the abstract, but also as organisational work that shall provide the material basis for the exercise of agency and which is to be facilitated through given (practical) material means or tools, as well as facilitated through (political) community norms and rules. In this regard, our approach through the SEAS project has involved utilising the potential of digital technologies through a multi-dimensional approach to content knowledge that integrates the following dimensions: conceptual, i.e., aimed to develop an effective and meaningful understanding of the concepts involved in sustainability and climate change issues; epistemological, i.e., aimed to enter the SSI sophisticated epistemological argumentations which refer, more or less implicitly, to a refined way of looking at modelling in climate science as well as to problematise a traditional and strictly mechanistic image of science; and societal, i.e., aimed toward a growing personal involvement in sustainability and climate change issues supported by the maturation of rational arguments for moving consciously through the political, economic, social, ethical, and moral aspects of SSI.

This is also in line with the fact that a significant part of life outside school is digital. The use of digital technologies is profoundly changing what it means to be literate and the kinds of competencies we need to fully participate in an increasingly digital world (Leu et al., 2016). Young people today have access to an almost infinite amount of scientific information, including contradictory information on key issues of climate change, leading students to reuse already available and possibly misleading information online (Solli, 2019), when evidence-based scientific consensus on climate change is presented alongside a range of competing populist narratives. However, digital resources may also support students in developing agency (e.g., Kajama and Kumpulainen, 2019) and critical inquiry (Echeverri and Sadler, 2011; Wiblom et al., 2019). Changes in ICT align with changes in culture that significantly change possibilities for participation, boundary-crossing, and the formation and negotiation of identity and agency (Erstad et al., 2016).

THE PRESENT STUDY

As part of our work as educational researchers and practitioners, we have operationalised the principles and ideas on making deep change and transformation as central elements of teaching scientific literacies through the Horizon 2020 project titled Science Education for Action and Engagement toward Sustainability (see text footnote 1) coordinated by the University of Oslo. The project's overall aims have been (1) identifying core principles and best practices required for creating and sustaining open schooling collaborations and (2) promoting scientific literacies and skills necessary to address real-life complex sustainability challenges.

SEAS (is one of the projects funded within the "Science with and for Society" pillar of the Horizon2020 EU Programme, where the EU Commission calls for the development of new science learning didactic, based on an open schooling approach, in which science learning processes are strongly linked to the students' participation in real-life science challenges in society, real research, and innovation circles. The open schooling idea was officially introduced within the EU context in 2015 by the report entitled *Science Education for A Responsible Citizenship,* which asserts the need to create and explore ways to expand science education beyond traditional school models (European Union, 2015). Open schooling calls for a re-definition of the role of schools. In particular, "openness" refers to the idea that schools have to become flexible structures, open to society, and should be able to make a difference in the world (European Union, 2015). SEAS interprets the open schooling spirit by putting at the core of the project the establishment of six open schooling networks across six countries. Indeed, the open schooling networks are thought to be the fertile ground for change.

To illustrate the ideas above as they connect to practice, and the implications they may have to science education, in the following sections, we first present a specific module of the project, developed as part of the Italian local network.

The Italian Local Network Approach

The Italian local network bases its activity on the implementation of modules designed in a previous Erasmus + project (I SEE)[2] whose aims were to develop skills for imagining the future and aspiring for STEM careers and to foster students' identities as capable persons and citizens in a global, fragile, and changing world (Branchetti et al., 2018; Tasquier et al., 2019; Levrini et al., 2020, 2021). The modules are based on an educational reconstruction of cross-cutting scientific topics, among which climate change, which are likely to be important in students' futures, both at the personal, vocational, and societal level. Specifically, the module on climate change was based on a 2012 Ph.D. thesis on climate change education, refined over time to reflect evolving aims and embedding innovative principles. Within the I SEE project, the module was taught to develop particular skills through science education in open schooling learning environments, called *future scaffolding skills*, referring to the ability to construct visions of the future that empower action in the present with an eye on the horizon (Levrini et al., 2021).

[2] www.iseeproject.eu

The evolving versions of this module are extensively described in Tasquier et al. (2016), Tasquier and Pongiglione (2017), Levrini et al. (2019, 2021), and Tasquier et al. (2019).

The challenge of developing *future-scaffolding skills* through science topics encounters the core of the SEAS project of supporting young people (and others) to develop sense-making resources and transformative engagement in and through addressing complex sustainability challenges. Due to this, the first pilot iteration consisted of a process of co-design and re-design of the climate change module within the larger scope of the SEAS project in order to elaborate on the meaning to embed SEAS principles and the transformative dimensions.

A foundational part of the SEAS approach was to develop and test open schooling practices using digital and non-digital tools and resources that support inquiry into complex environmental, SSI at the student, teacher, and network levels. These tools were chosen among the ones already developed in earlier projects by SEAS partners (i.e., cCHANGE).[3] Besides, the project has, in its ambition, also, the idea of extending the set of tools taught within SEAS to external existing tools in order to understand how to shape the use of general tools by embedding SEAS principles and the transformative dimensions. For the first pilot iteration, the Italian Local Network selected two tools that were considered relevant for the context and that will be presented in the next section.

The Climate Change Module

The SEAS approach and principles introduced in the previous sections guided the re-design of the teaching module on climate change, which targeted secondary school students in grade 12 (17–18 years old). The module was situated within the context of *Piano Nazionale Lauree Scientifiche* at the Department of Physics and Astronomy of the University of Bologna and was implemented along 6 afternoons (once per week) in the period of January-February 2020.

The module was organised in a multi-layered structure that considered some important characteristics of the theme of climate change (Tasquier et al., 2016, 2019; Tasquier and Pongiglione, 2017; Levrini et al., 2019, 2021). Indeed, climate change is a topic that is:

- *Complex*, because the climate is itself a "complex system" resulting from the interactions that occur on an enormous variety of spatial and temporal scales across the various and many sub-systems that compose it; in fact, in a complex system, the interactions between the components of the system can follow not only a linear cause-effect logic but also a circular cause-effect logic in which one component acts on another and this, in turn, feeds back on the former;
- *Multidisciplinary and interdisciplinary*, because it involves many scientific disciplines, among which are climatology, meteorology, physics, chemistry, biology, and so on; this means that there are many conceptual difficulties that hinder student's understanding of the scientific contents related to climate change, like greenhouse effect, and all of these have different epistemological models that belong to the feature of the disciplines;
- *Multidimensional*, because it does not touch only the scientific dimension but also involves political, economic, and personal, affective, psychological, cultural, and ethical dimensions;
- *Multi-scale,* since the causes and consequences are placed on different spatial-temporal scales and because it concerns decisions and actions both locally and globally, where it is not easy to recognise the role of individual as a causal agent;
- *Future-oriented and future-relevant*, because it represents a widely debated social challenge for its implications for the future and its analysis to develop skills to imagine possible and desirable futures and is guided to use such images of futures as a driving force in their life, in order to activate their resources, engage in social challenges, and guide their choices and actions in the present;
- *Transformative*, because it is changing our environment but also because responses to climate change require a combination of technological innovations, institutional reforms, behavioural shifts, and cultural changes; those changes require a shift from a vision of people as objects of change to people as *subjects* of change in a genuine and mutual relationship with the environment.

The overall structure and agenda of the modules are summarised in **Table 1**.

In order to embed a transformative dimension to the module, two tools were integrated into the course agenda, taking supplementary roles: (1) the *cCHALLENGE platform*, implemented within the SEAS project by cCHANGE (Norway) (O'Brien and Sygna, 2013)[4] and (2) the role-playing activity World Climate: A Role-Play Simulation of Global Climate Negotiations developed by Climate Interactive at MIT Sloan in Cambridge, Massachusetts (US), called c-ROADS (Sterman et al., 2015).[5]

These two tools were set together to activate a particular back and forth dynamic between individual action and collective impact, by giving support to the agentic role of individuals in shaping the system. cCHALLENGE is a web-based tool aiming to trigger a reflexive and experimental process for transformative learning. It builds upon the notion of *three spheres of transformation* (O'Brien and Sygna, 2013), which conceives transformation as a systemic relationship between personal, practical/technological, and political change. Through engagement in cCHALLENGE activities, participants (students and teachers) experiment with personal change through 30-day projects that are followed up during and after the 30-day period in the classroom and out-of-school activities.

The cCHALLENGE invites students and teachers to experiment with change, where participants select an everyday habit that they wish to change for 30 days—e.g., doing more exercise, eating less meat, avoiding plastic products—and encourages and scaffolds a reflective process during those

[3]https://cchange.no

[4]https://www.cchallenge.no

[5]https://www.climateinteractive.org/tools/c-roads/

TABLE 1 | Climate change course agenda.

22.01.20	• Introduction to Cchallenge
	• Introduction to climate change: the scientific research and the new terms of the scientific controversy [Climate Science, Math, and Physics]
29.01.20	• Experiments on examples of interaction between radiation and matter [Experimental Physics]
05.02.20	• Experiments on the construction of a Greenhouse model [Experimental Physics]
12.02.20	• Introduction to complex systems, modelling and simulation [Science of complex system, Math and Physics]
	• Analysis of a scientific text, conversion into causal map and identification of feedback loops [Linguistic, logic and Physics]
19.02.20	• Political and Economic scenarios: Role-play with a climate simulator [Political, Economic and Sociological Science and Physics]
07.04.20	ONLINE conclusion after the stop due to the pandemic

30 days. Participants get to share their experiences and stories in the form of blog entries, describing possible solutions, new ideas, and courses of action together with evidence of change. In addition, participants get feedback and prompts aimed at triggering reflection. In this way, cCHALLENGE fosters collaboration, co-creation, and dialogue among the local actors involved in the challenge, who, together, generate new stories about solutions and the role of people within the climate dynamics. These emerging *narratives of change* become visible and shareable as textual objects that mediate both individual and collective learning in learning trajectories across places, time, and encounters with experiences of phenomena, people, and texts. The change experiment thus enables participants to become aware of the challenges and opportunities that emerge in the process, their influence on others, and to explore their own role in changing unsustainable systems and practices. Although the cCHALLENGE tool is originally conceived as a digital platform, for this project, a *Paper* and *Pen* version was developed and used.

The C-ROADS is a free computer simulator that has aims to help individuals understand the long-term climate impacts of national and regional greenhouse gas emission reductions. This tool is suggested to use as part of the "World Climate Simulation," an interactive role-play where the young participants can play the roles of UN climate negotiators who are working to create an agreement to limit global warming. Participants play the role of negotiators for various nations (or blocs of nations) and they must consider their national interests as they negotiate a global agreement to mitigate climate change. To do this, participants receive briefings to help them understand the interests and objectives of the nations they represent. During the simulation, they play some rounds where they negotiate with one another to agree on commitments for greenhouse gas emissions reductions from the present through 2100, long enough to capture projected population growth, economic development, and important climate impacts (Sterman et al., 2015). During the role-play, students are guided toward the following stages: (i) allocation of roles linked to groups of countries or stakeholders that take part in climate-related decisions (e.g., non-governmental associations, oil industries, etc.); (ii) in-depth analysis of related data of countries and stakeholders; (iii) negotiation between the parties to decide which measures to take and on what timescale; (iv) data introduction into the simulator and projection of scenarios; and (v) renegotiation of objectives based on scenarios.

The C-ROADS was used to help the students move from their individual challenges to a collective perspective and then come back to evaluate their challenges with new perspectives and insights. In this sense, the interaction between cCHALLENGE and C-ROADS is aimed at activating a back and forth dynamic between individual and collective aspects from multiple perspectives.

The Context and the Sample

The implementation of the module was situated within the context of *Piano Nazionale Lauree Scientifiche* at the Department of Physics and Astronomy of the University of Bologna. The module was tested with a class of 20 voluntary students (11M, 9F; 17–18 years old) who for six afternoons (one time per week) attended the climate change course in the period January-February 2020. The course was interrupted before the last meeting, due to the closure of the schools because of pandemic restrictions. The final meeting was instead conducted as a final online activity, which took place around 1 month and a half after.

The module was designed, implemented, and orchestrated in concert with the stakeholders participating in the Italian local networks, among which some teachers at the schools involved in the project, and a collaboration at a consortium level with the Norwegian local network (in particular the cCHANGE team) was foreseen for the implementation of the cCHALLENGE tool.

Research Questions

The implementation described above was monitored and analysed to contribute to the overall research problem that guides our study: *How can we support school students to engage critically with scientific knowledge and expertise to foster decision-making and to be enabled as agents of transformative change, as current complex societal challenges require*?

In this study, we operationalise this overall problem in terms of the following research questions:

> RQ1: What perceptions and awareness toward change do students construe across the climate change module, and how can they be traced and recognised in students' discourses?
>
> RQ2: What opportunities for fostering agency for change can be created through teaching climate change and sustainability?

The first research question is more descriptive-oriented and to some extent contextual. The second research question is more interpretative-oriented and aims to provide a contribution to science education by exploring to what extent transformative

TABLE 2 | Data collection.

Questionnaires	This typology of data consists of pre- and post- questionnaires assessing cCHALLENGE, and a final questionnaire about the course. The questionnaires were composed of close-ended and open-ended questions aiming at investigating various climate change characteristics taken up through the activities of the unit. There were also questions asking the students to self-reflect and self-position on specific aspects of relevance to scientific literacy and change-making, like for example their level of awareness and knowledge with respect to climate change. A pre-existing questionnaire already validated in previous iteration (e.g., Tasquier and Pongiglione, 2017) with some re-adaptation to the new context was used as final questionnaire in this study.
Artefact collection	This typology of data involved any artefact produced by the students during the whole course including: blogposts on the cCHALLENGE platform; written boards and/or sheets used for sharing tasks during the lessons, support students in fixating their thoughts and/or positioning with respect a collective questioning activity; written maps and text documents; and teacher assessments.
Classroom observation	This typology of data involved the audio-recording of the lessons, the groups' work and the collective discussions taking place during the course as well as field notes and diary boards written during the debriefing sessions taking place among the researchers after each lesson.

skills and attitudes can be triggered within a teaching-learning science module explicitly designed to support change-making.

METHODS

Data Collection

The data were collected and analysed through a variety of tools to allow checking against one another, corroborating evidence, and evaluating the extent to which all evidence converges (Anfara et al., 2002). In particular, we collected and analysed three different types of data: questionnaires, artefact collection (participants' products), and classroom observations (**Table 2**).

Analytical Approach

For the analyses in this study, we mainly considered the questionnaires, the blog posts published on the cCHALLENGE platform, and the audio-recording of the collective discussions. Field notes were considered as a source for data triangulation. All the texts were compiled and tabulated so as a common analytical strategy, as described below.

Given the sample and the research issues, we opted for a semi-qualitative methodology of data analysis rooted in *Grounded Theory* (Glaser and Strauss, 1967). As part of this, a *thematic analysis* was carried out across all data sources (Braun and Clarke, 2006). In particular, we assume the approach of *reflexive thematic analysis* where a mixed inductive/deductive approach is used, combining both data-driven clustering and theoretical hypothesis (Braun and Clarke, 2019). The themes emerging from the analysis were considered as stories about particular "*patterns of shared meaning*" across the dataset (Braun and Clarke, 2019, p. 6).

This analysis has been performed as the first stage of an iterative process. In this sense, this level of analysis does not aim to produce either coding or operative categories but aims to search for *sensitising concepts*[6] (Glaser and Strauss, 1967; Charmaz, 2003), the purpose of which is to allow researchers to sensitise to the participants' perspectives, allowing us to capture and describe how participation in the unit, including the use of tools, are experienced and impact the students' worldviews and narratives, guiding further rounds of increasingly structured implementations. The data were thus analysed through an iterative process that included bottom-up debriefing phases designed to identify emergent themes and to generate initial interpretative ideas.

To reach an acceptable level of internal validity, the analysis was conducted through a triangulation process that, in line with recommended practices (Anfara et al., 2002), included member check and peer debriefing with researchers in science education and some collaborators of the network. In particular, the first phase concerns the analysis of the close-ended questions coming from the two post-questionnaires that give us an overall picture of the iteration. The second phase concerns the organisation and the grouping of all students' answers coming from the different data sources into an excel file, where each sheet belongs to a data source. Within each sheet, the rows represented the students (anonymity was respected but not losing information on gender and age) and the columns represented the different areas of answers (e.g., comments on their own challenge in the cCHALLENGE, the link between cCHALLENGE and the role play about climate negotiations, etc.). The organisation of the grid allowed us to follow both individual profiles and common patterns related to an area. The third phase was represented by reading all the answers. This reading led to the selection of pieces in which the students put much emphasis and where recurrences were observed. In this passage through the data, some recurrent patterns emerged, which we identified as top-down macro-phenomena whose appearance was tested against the whole corpus of data. The fourth phase consisted in trying to interpret the data in terms of the appearance of a transformational dimension, where we used the *model of the three spheres of transformation* (O'Brien and Sygna, 2013) and tested whether it was possible to identify the three levels of transformation (practical, political, personal).

RESULTS

Students' Perceptions of Climate Change and Their Agentic Role

First, we present an overall picture of students' reactions with respect to some selected aspects of the course (e.g., perception

[6]"Sensitising concepts are those background ideas that inform an overall research problem. [. . .] Sensitising concepts offer ways of seeing, organising and understanding experience. Although they may deepen perception, they provide starting points for building analysis, not ending points for evading it." (Charmaz, 2003, p. 259).

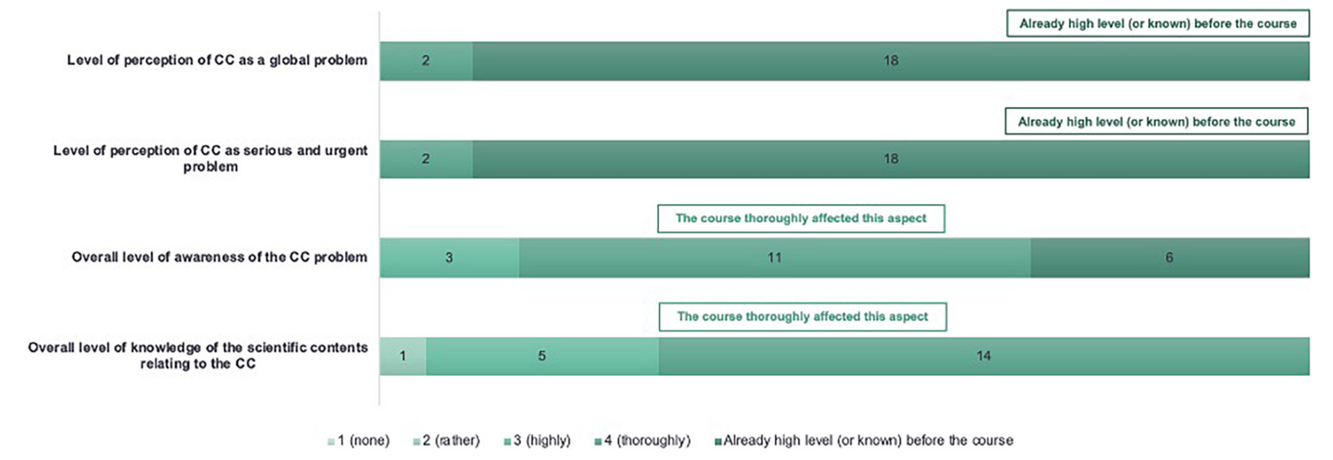

FIGURE 1 | Students' rating about how they approach climate change—(Rating scale: 1-none; 2-rather; 3-high; 4-thoroughly; Already high level before the course).

of climate change as a global problem) and of how they dealt with their challenges. Findings presented here, thus, directly address RQ1 above and draw from students' answers to the close-ended questions of the two post-questionnaires and related extended comments.

Students were asked to rate the extent to which the course impacted the way they perceive the issue of climate change.

Figure 1 shows that most students, already before the course, perceived climate change both as a global problem and as a serious and urgent problem. Comparing this result with students' perceptions of the problem in previous editions—this is a course that has existed for several years, having been administrated in its diverse versions from 2012 to 2020 with the exception of 2019 (Tasquier, 2015; Tasquier and Pongiglione, 2017)—the current trend represents a turning point. Until 2018, the students who attended the course had a low-medium level of perception about climate change being a problem. This contrasts with the scores in the current set showing a clear perception of the problem already before the course unit. This change in perception observed at the local level across the years is compatible with results presented in the recent Special Eurobarometer report of 2019, which reveals that 93% of Europeans see climate change as a very serious problem (European-Commission [EC], 2019). The Eurobarometer report also declares that, among these, 60% of respondents think climate change is one of the most serious problems facing the world, a percentage that has increased 17 points since 2017. In terms of perception of the problems, climate change has overtaken international terrorism (54%) as the second most serious problem after poverty, hunger, and lack of drinking water (71%) (European-Commission [EC], 2019).

The course has the most impact in terms of the overall level of awareness of the problems and, particularly, on the level of knowledge of the scientific basis of the problem. Although not sufficient, this is important to students' engagement in deep transformative change processes.

Figure 2 shows that, with respect to the level of awareness of the problem, the students were generally aware enough about climate change impacts and consequences before the unit. This result is in line with results from the recent large-scale climate survey launched by the European Investment Bank (2020), which reports that people in EU Mediterranean countries have a high level of perception and awareness about the impacts of climate change on their everyday lives. In Italy, this percentage is about 94%.

Figure 2 also suggests that the course had the highest impact on students' level of awareness about the causes of climate change, which was highly rated, while showing lower scores concerning the level of awareness about possible solutions. We discuss these results further below as these need to be considered in connection with responses to another set of questions.

Coming back to the level of knowledge of scientific concepts, **Figure 3** shows how students rated their understanding with respect to some important concepts of the course. In particular, the two concepts that were perceived as most important were the (i) bond between the absorbance of the atmosphere and the temperature rise, and (ii) the concept of feedback.

As argued in previous research (Tasquier, 2015; Tasquier et al., 2016; Tasquier and Pongiglione, 2017), these observations on the students' knowledge of scientific concepts represent an important aspect in the interweaving of the disciplinary dimension with the epistemological and the societal dimensions of learning about climate change. In particular, considering the atmosphere as a body that interacts and, therefore, absorbs and emits radiation, thereby influencing the global temperature of the whole system, is a key point that allows the students to tackle the idea that there can be a crucial anthropogenic role in the changing of the system (Tasquier, 2015).

Concerning the concept of *feedback*, previous research (Barelli et al., 2018) discusses how feedback is indeed a multifaceted term that has currency in everyday use as well as in science, as well as in social phenomena (e.g., evaluation/assessment situations). The shift from the idea of feedback as a unidirectional response to a stimulus toward a more explicit idea of circular causality is a key moment in making the epistemological shift toward a perspective

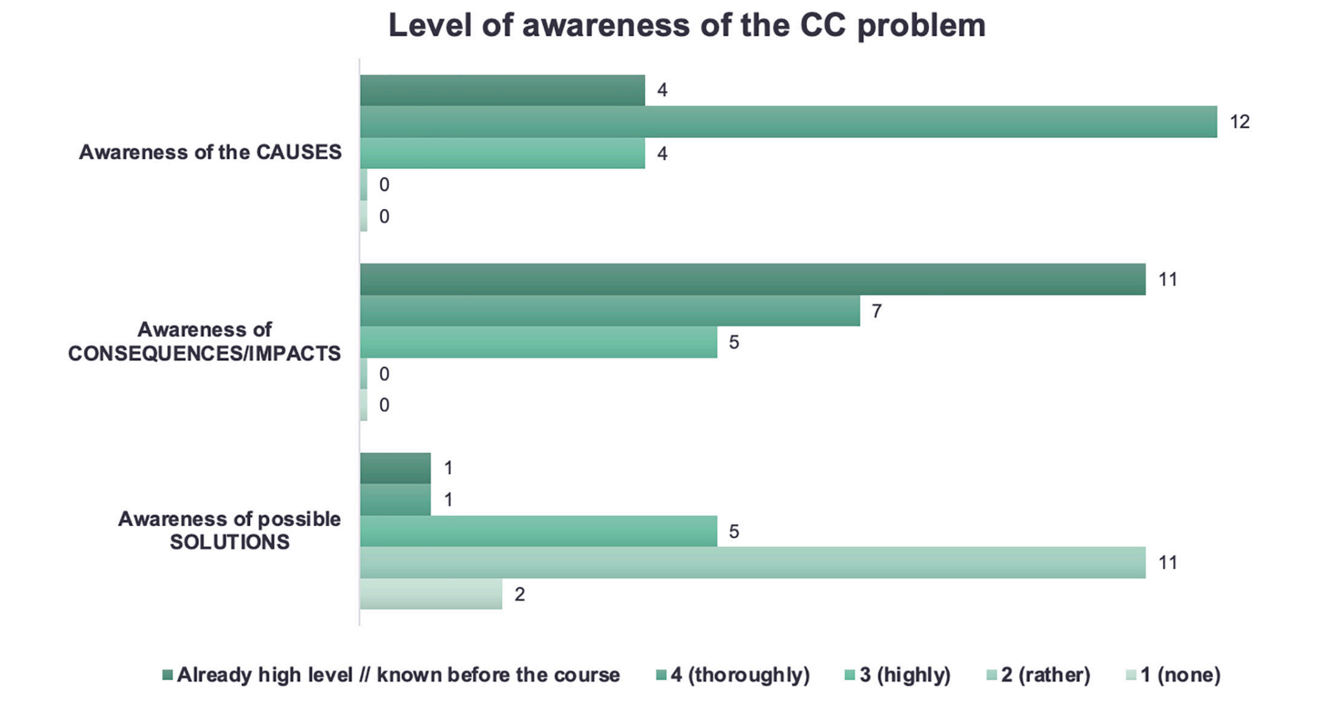

FIGURE 2 | Students' level of awareness of the climate change problem—(Rating scale: 1-none; 2-rather; 3-high; 4-thoroughly; Already high level known before the course).

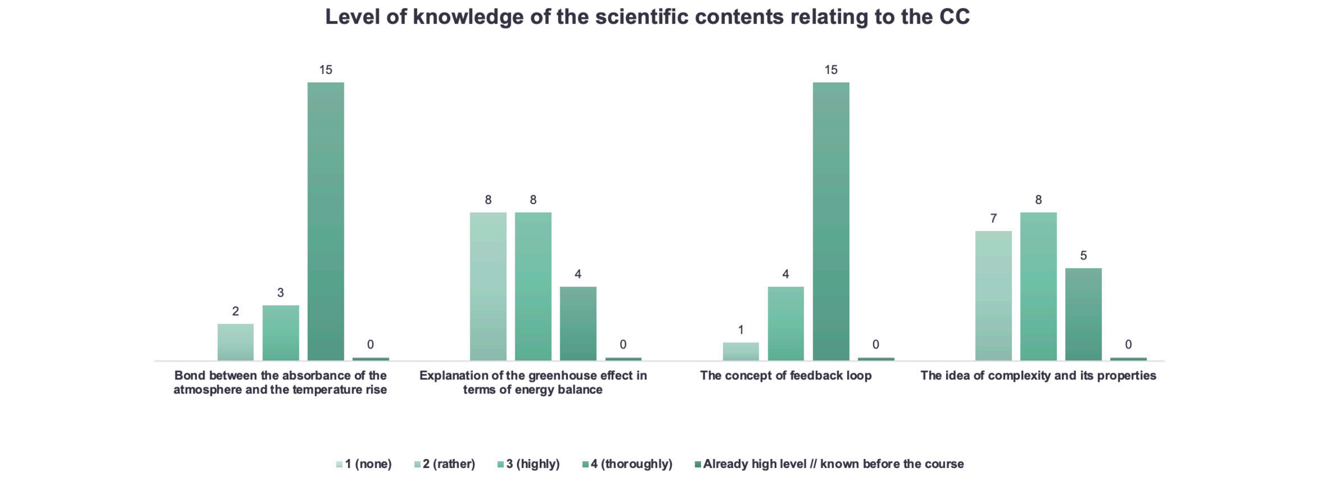

FIGURE 3 | Students' level of knowledge of the scientific content related to climate change—(Rating scale: 1-none; 2-rather; 3-high; 4-thoroughly; 5-Already high level//known before the course).

that acknowledges the systemic nature and complexity of the issue. The concepts the students displayed an understanding of are thus important for what has been referred to as *causal knowledge* (Tasquier and Pongiglione, 2017), which involves a dynamic relationship between cause and effect and helps in understanding the role of humans as causal agents in climate dynamics and, in the second order, may contribute to triggering willingness to take pro-environmental actions. In this study, we did not go deeper into this research aspect but, based on results from a previous study (Tasquier and Pongiglione, 2017), we consider the development of this knowledge to have the potential for triggering agency.

An interesting result is that the answers to the questions are related to the level of understanding of the role of individuals.

As shown in **Figure 4**, if on the one hand, all students seemed to have understood the role of individuals in being part of the problem, and the same level of understanding was not expressed with respect to the role of individuals as being part of the

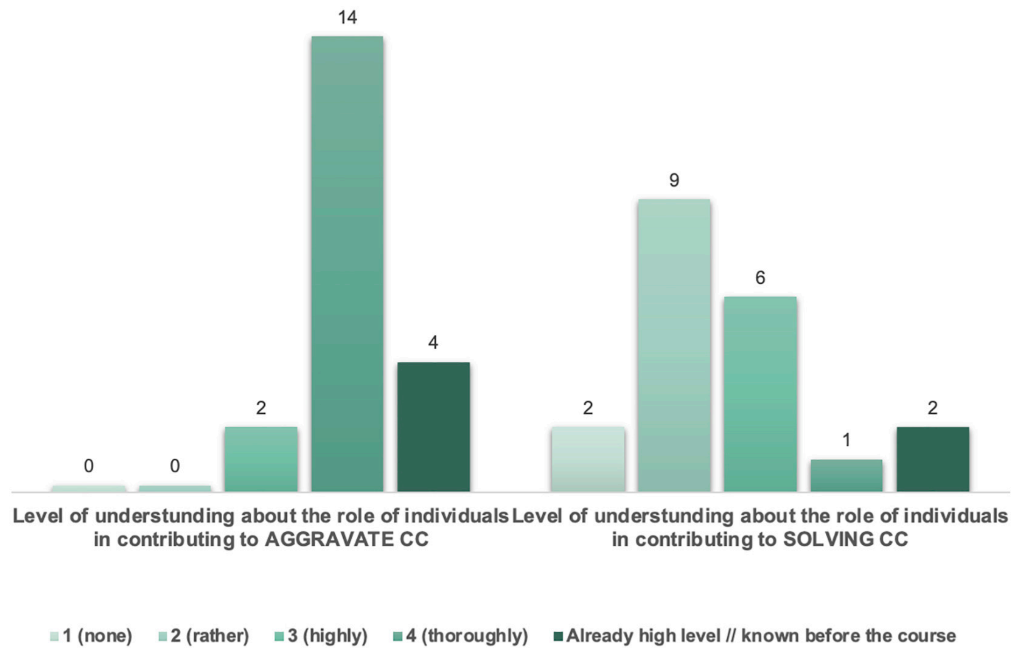

FIGURE 4 | Students' level of understanding about the role of individuals—(Rating scale: 1-none; 2-rather; 3-high; 4-thoroughly; 5-Already high level//known before the course).

solutions. This result can be also related to the one presented above concerning their (low) level of awareness about possible solutions to climate change (**Figure 2**).

This overview shows that, regarding the development of awareness and knowledge about the scientific contents of climate change, there were some important conceptual and epistemological shifts made by the students, especially toward the science of complex systems and their properties (e.g., awareness about the concepts of feedback loops and circular causality). Based on previous results from Tasquier and Pongiglione (2017), these elements of awareness and knowledge, which we refer to as *causal knowledge*, are foundational for triggering the emergence of a willingness to act toward climate change. However, we can see that the most critical point remains how they feel aware of possible solutions and about the role of individuals in determining solutions for changing the system.

Concerning this point, as a final question, we asked explicitly the students to self-reflect if there was a change in their perceptions of individuals' agentic role in climate change and if the module, with its articulated structure, contributed to activating a level of awareness about the importance of the agentic role of individuals.

As shown in **Figures 5A,B**, at a level of self-perception, the students perceive that the module in its global articulation had a significant impact on their initial belief about the possibility for individuals as agents of change when it comes to the climate change discourse.

The next section provides a closer look into students' ideas by analysing their open (textual) answers and discussion in order to find a refined way for tracing the presence of change.

Tracing the Change

As we argued in section "The Climate Change Module," there were tools and activities across the whole unit—including cCHALLENGE—that were designed with the explicit goal of triggering reflection about the individual/collective dynamics and the role that individuals can have in changing the global system.

Through engagement in cCHALLENGE, the students experimented with personal change through 30-day projects that were followed up through classroom and out-of-school activities. **Figure 6A** shows an overview of the diverse themes chosen by the students, and **Figure 6B** shows the level of commitment they have expressed at the end of the cCHALLENGE. Measuring the *level of commitment* is particularly relevant for an understanding of the transformative potential of science education, for, as it has been discussed with regards to the importance of supporting agency through education (Stetsenko, 2016b), "an activist commitment to a sought-after future created and realised in the present" is crucial in bridging "the gap between the narrowly understood natural science and the ideological-critical orientation aimed at social transformation" (p. 287) that is needed in tackling climate change challenges.

Figure 6A shows that there was a wide variety and diversity of areas with respect to the cCHALLENGE; this seems to give back an image of authenticity in evaluating the change according to its personal context. **Figure 6B** shows that students' level of commitment toward their challenge was quite at a high level.

From the analysis of students' answers to the open-ended questions, we discovered that cCHALLENGE represented a quite unfamiliar tool to be used within a climate change course, which

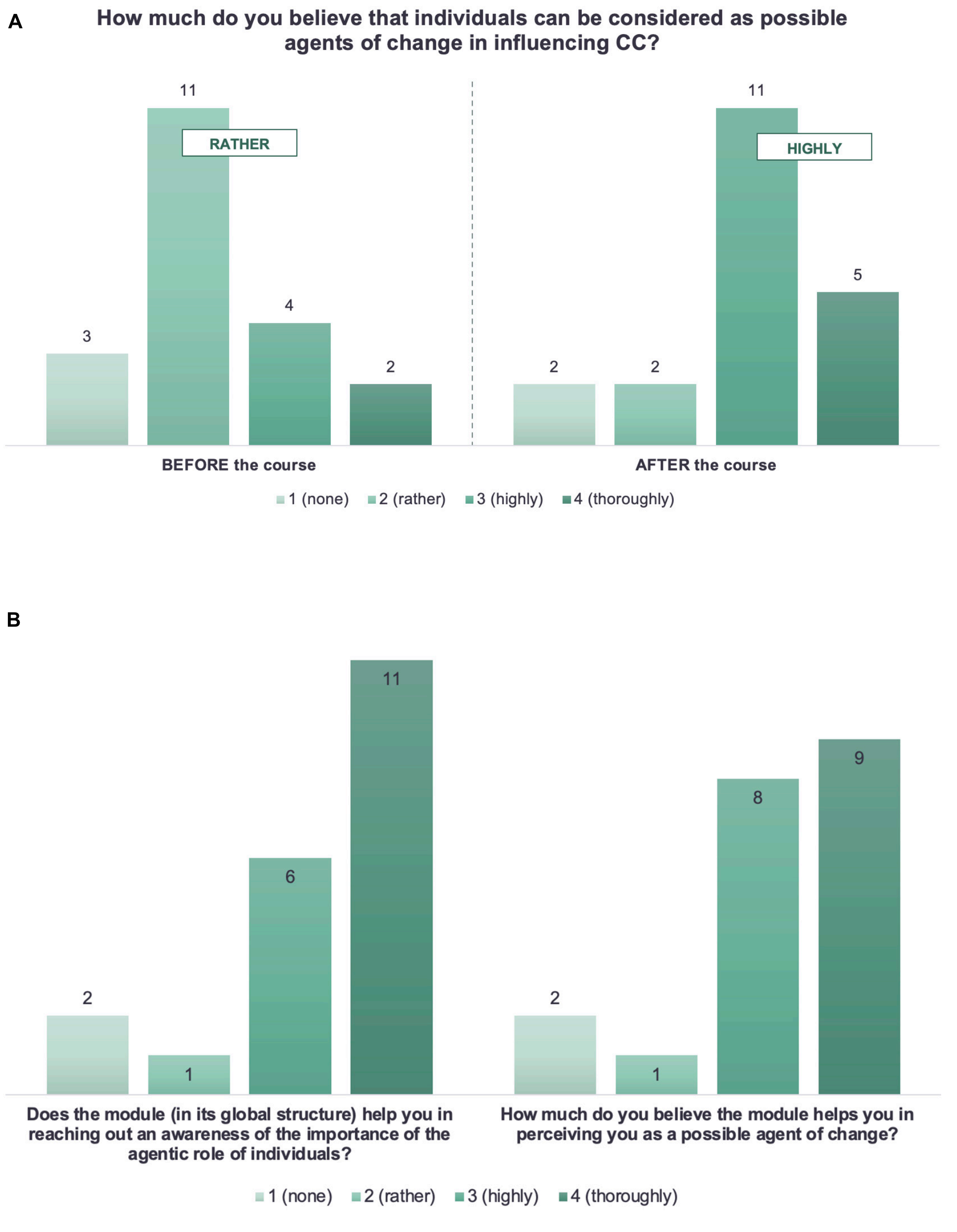

FIGURE 5 | (A) Students' perceptions of the agentic role of individuals in climate change (Rating scale: 1-none; 2-rather; 3-high; 4-thoroughly). **(B)** Students' perceptions of their change—(Rating scale: 1-none; 2-rather; 3-high; 4-thoroughly).

initially created a general sense of distrust among the students. However, across the whole unit, students' perceptions evolved, and a sense emerged that the tool indeed became particularly meaningful in combination with the role-play simulation about climate negotiations.

To uncover this development and change in the students' perceptions and the implications this has for their learning toward change-making through science education, in this section, we present findings from the second phase of analyses (see section "Analytical Approach"), which focuses on uncovering patterns in students' written responses to the questionnaires and oral reflections. Below, we present these patterns and how we interpret them as elements of interconnection are able to trigger dynamic relationships between individual attitudes and a collective dimension.

Connections and Continuity Across Knowledge Sources

In talking about their cCHALLENGE experience, the students draw connections between multiple contexts that enhance their awareness of their position on local and global sustainability challenges. Students showed awareness of connections and tensions between their own challenges and the broader collective dimension.

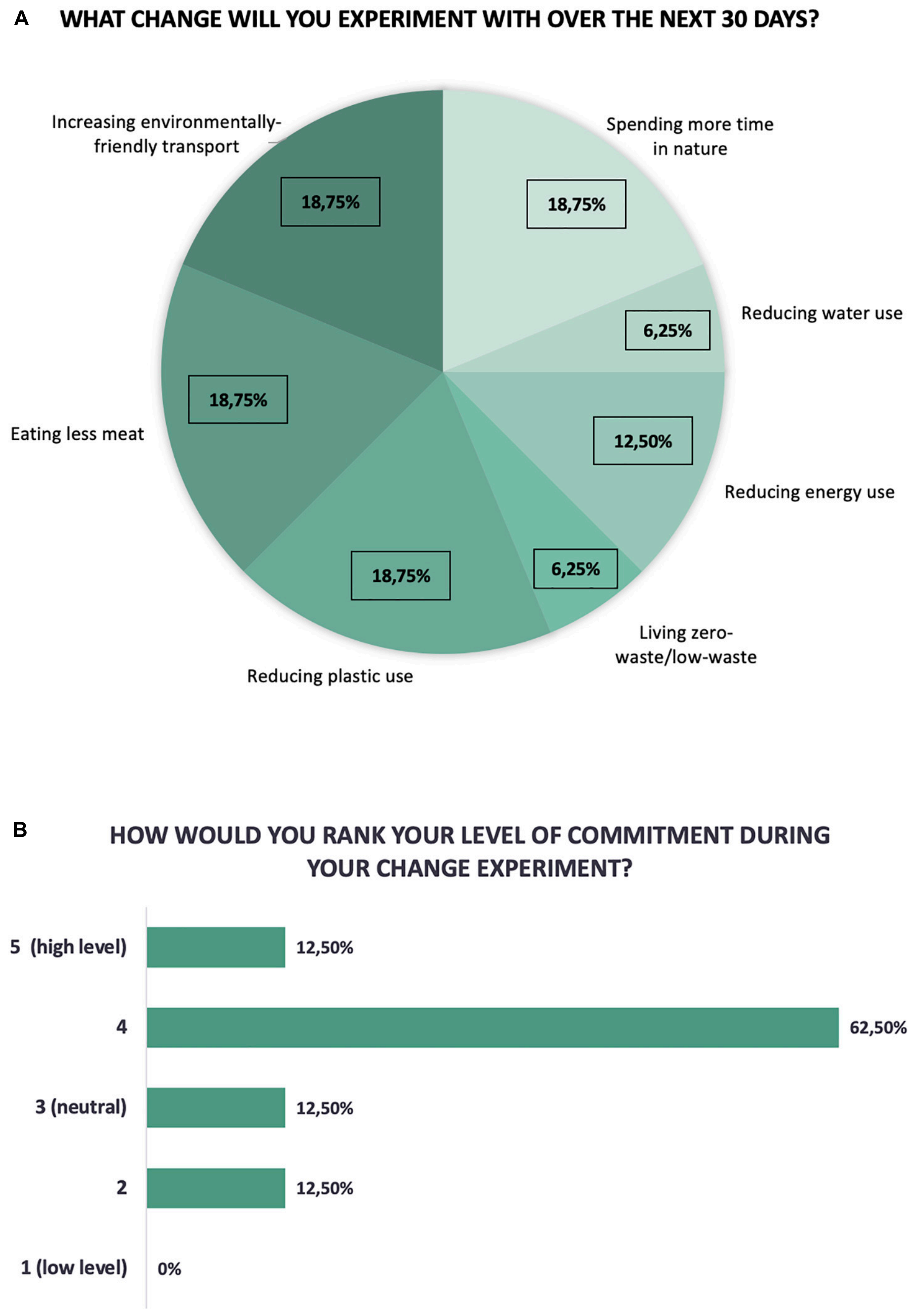

FIGURE 6 | (A) Distribution of the students over different challenges. **(B)** Students' level of commitment.

First, we observed how students referred to diverse sources of knowledge with critical considerations on the validity and application of scientific knowledge. In multiple utterances, students draw upon scientific arguments that include reference to socio-scientific considerations, as a means to elaborate on their motivation and drive to pursue change. Indeed, when talking about their approach to the challenge, they often showed awareness in supporting the sustainability challenge not merely by taking up the recommended practice of reducing meat consumption but by drawing on the wealth of disciplinary knowledge on the subject, as it is represented for instance by the sentence of this student:

> *"In my challenge I have chosen to reduce the consumption of meat. A friend of mine have lent me some books and reading them I inquired about how to have a balanced diet while reducing meat consumption. I have made a food culture thanks to these books. They are not books written by radical people. I liked them and they gave me a lot of confidence because they are books by university*

professors who are experts in nutritionists, all balanced people who made me find a way to approach a diet with little meat, so in the end it is not such a difficult challenge -SF.[7]*"*

Recognising the central role of scientific knowledge for interpreting climate change seemed to create a sense of continuity in their awareness of the problem, between the urgency of the problem they perceived from the public debate and the need to give it a meaning by grounding it in the discipline. Understanding the problem by situating it within the domain of science gave substance to their interest and made them find arguments for defending their position not only in terms of a significant ideological choice. See the following except for example.

"Honestly, the challenge was difficult. I realised that it is not that easy to change a habit and that it takes solid motivations. I found them in what I was studying in this course, in how the climate data was presented to me, in the fact that I understood the role of the atmosphere in the global warming, and I was able to connect the change in the atmosphere with the role of our global actions. The feedback mechanisms have helped me to understand that in the cause-effect links between the single element and the community there can be effects of balance or amplification. Knowing that there was a foundation in what I was doing helped me in finding meaningful motivation—SM."

So, the relationship with scientific knowledge was established in two ways; on the one hand, the scientific knowledge about climate change they encountered in the course served as a motivational factor for the challenge. On the other hand, the challenge was experienced as an entrance for going more in-depth specific knowledge aspects related to climate change (e.g., food consumption).

In referring to knowledge, there was another element of continuity. Indeed, an interesting aspect is that the students did not refer only to the construction of new knowledge but also to an alignment with previous knowledge. Below is an example:

"*I chose to do my cCHALLENGE on food and I chose it because when I was asked what challenge I wanted to face I immediately thought of Jonathan Safran Foer's book [We Are the Weather: Saving the Planet Begins at Breakfast] that I had read a few months ago. I was very impressed reading that eating meat has such a great weight, nobody ever tells me that. That book was much instructive and I immediately connected my challenge to that. because even if you know that you have to change, even if you read it from a book like the one that shocked me at the moment, even if you read how problematic is the impact of livestock, then when you have to do it concretely it is not so easy, you need a chance and so—SF."*

However, as a pattern that is recognisable in the data, in those moments of alignment with previous knowledge, the students refer always to a knowledge acquired outside school science classes, and mainly through in-depth readings that they made for personal scientific interest during the extra-school time.

[7]SF, student female; SM, student male.

Understanding Complexity Across Climate Change Dimensions

A second aspect, recognisable as a pattern, is the ability of the students to recognise a plethora of different actors who may have different roles in addressing the climate problem, like, for example, the importance not only of the role of professional experts but of political decision-makers and citizens, as exposed in the following excerpt:

"My perception on climate change has varied thanks to these experiences. I am now convinced that there is a need for action by both the policies of the states but also by all those involved in the problem. We need careful choices on the part of politicians, the ability of climate professionals to find increasingly accurate models and also to find technologies that can tackle problems, but we also need the contribution of individuals who as citizens act together and in same direction. Only in this way is it possible to achieve effective and not negligible results—SM."

Recognising the multi-dimensional and multi-actor nature of the issue led the students to identify how, in the collective dynamic, it is important to distinguish a variety of drivers of change that can act at different scales. When passing through students' texts, we noticed that the identification of the possible dimensions of actions as well as the types of actors, roles, and communities represent an important factor for distinguishing where and how it is possible to impact and for creating a sense of empowerment with respect to the issue, as shown by the excerpt below:

"Who you are identifies your responsibilities, your role as an individual determines the weight of your choices. I took up the challenge as an 18 y.o. and my responsibility was to find a way to change a habit and generate a ripple effect in my communities, which are my friends, my family, my class. The teacher of the course, for example, brought an educational message about the climate to a lot of students like me who did not know each other and who spread it to their families and in their schools. The teacher who made us play with the simulation on the climate negotiations is in charge of negotiating at the COP, if you carry out an agreement in those contexts this has enormous consequences on the countries. If you are a politician your challenge is to decide how to invest your country's money, whether to invest in renewable energy or other and this has an impact not only on your country but also on the global balances. The scale you act on depends on who you are, but I understand that what you do as individual has consequences on the collective dynamic—SM."

So, in this example, the aspect of recognition triggered the creation of new relationships across the three spheres of transformation, which involved the inclusion of themselves in the problem, as actors. However, the issue of who should drive the change or should be responsible for it still remained an aspect of polarisation between the global and individual levels, see, for example, the excerpt below:

(i) Institutions as the drivers and responsible of change, (example excerpt: *"It is true that the single daily and individual choices are a beginning, but without a global action driven by the States it is not enough—SM"*);

(ii) Individuals as the drivers and responsible for the change (example excerpt: *"Great changes are brought by individuals. Only starting from individual behaviour can we arrive at a truly collective change—SF"*).

The Ethical Dimension in Science-Based Decision-Making

Another important insight gained during the whole course was the importance of including values in science. In particular, we have already seen the interplay between cCHALLENGE and the role-play simulation about climate negotiations in making science-based decisions. However, the students underlined how there is also another aspect: science-based decision concerning socio-scientific aspects cannot be considered neutral from a value perspective, as illustrated in the excerpt below:

> *"Climate decisions cannot be neutral, there are data and facts but making decisions implies bringing values into play. . . to stay within 2°C we need developing countries to do their part too. I was able to put myself in the perspective of these states and I understood that it means asking them a great effort with few resources. We asked the US to make available an economic fund that they did not want to make available. So. what are you doing at this point? When you know the data, not making choices is still making choices—SF."*

This discourse on climate change implies the involvement and the opening of decision-making scenarios. The request to make choices both in the cCHALLENGE and in the role-play simulation about climate negotiations opens toward making the relationship between personal, social, and affective values more visible as inherent in the making of decisions. In discussing the possible impacts of climate change in possible scenarios, the students realise the importance of recognising actionable implications of climate data, which suggest the need for action:

> *"The challenge made me understand that the time is coming when we have to make a choice and that to have an impact it will have to be made massively. absurdly, we are deciding whether to take advantage of the time we have left to live in a temporary economic comfort zone as long as we can and then suffer disaster when it arrives (hoping it will not be with us) or if we have the strength to give up something to radically change course for a greater common good. The difference is that this is not a family rule coming from my parents, the (climate) data tell me this—SF."*

However, it is important to point out that, even if this represents a crucial point, according to some well-known results, we are not able to establish to what extent knowledge of science relates to decision-making processes (Kolstø, 2001; Nielsen, 2012). Moreover, as discussed by Levinson (2006), evidence can have different roles in different cases, and scientific evidence has no self-evident role in the resolution of contested issues. People make judgements on climate knowledge in culturally based interpretive frameworks that shape what is held as valid and trustworthy knowledge (Hulme, 2015). From an educational perspective, however, these insights further reinforce the view that dealing with climate change by addressing its intrinsic societal nature provides an opportunity to negotiate scientific knowledge, while also making students aware of the complexity of SSI and helping them to develop skills to take part as citizens in a democratic society through discussing and evaluating different viewpoints on specific SSIs in a school context (Sadler and Zeidler, 2005). At the same time, these discussions tended to go beyond the negotiation of different points of view by recognising the need for action in a limited timeframe. The need for action recognised by the students is what drives and legitimises the discussions.

Summary

From the analysis of the corpus of data, it was possible to build a story around three recurrent patterns that are identifiable of ways able to trigger a dynamic relationship between the individual attitudes and agency, on the one hand, and a collective socio-material context for those attitudes and agency to emerge and take shape, on the other hand, which are the following:

(a) awareness in addressing climate change and sustainability challenge not merely by following a recommended practice in personal everyday life but by recognising the wealth of disciplinary knowledge as a resource to be drawn on;
(b) ability to recognise a plethora of different actors who may have different roles in addressing the climate problem, like, for example, the importance not only of the role of professional experts but of political decision-makers and citizens;
(c) recognition of the fact that the inclusion of science-based decisions concerning socio-scientific aspects cannot be considered neutral from a value perspective. The disciplinary knowledge referred to in (a) thus has no self-evident role in the mesh of knowledge, values, and social complexity.

Summing up, this analysis highlighted that it was possible to connect knowledge and behaviour (agency) by the following means: (i) opening science to real problems without losing the authenticity and authority of scientific knowledge; (ii) recognising the multi-dimensional structure of socio-scientific issues (SSIs); (iii) including *values* into scientific reasoning which trigger hints of democratic participation; (iv): engaging students in inquiry with tools supporting students in exploring complex issues across the practical, political, and personal spheres.

Interpreting the Identified Changes by Using the Model of the Three Spheres of Transformation

In the previous stage of analysis, we traced emerging patterns throughout the students' narratives and stories as they moved from a sense of mistrust to a more fluid engagement with the tools in the unit. The analysis suggests that the students' experiences in the course, embedding the use of tools like cCHALLENGE and the role-play simulation about climate negotiations, created a context open to foster skills and insights important to trigger transformative changes through science education.

To make more visible this transformative potential, in this phase of the analysis, we take the ***model of the three spheres of transformation*** (O'Brien and Sygna, 2013) as a starting point and inquire into the possibility of identifying examples of the three

TABLE 3 | Exemplary sentences.

Students' words	Example of possible markers for recognising belonging and/or transitions
Practical sphere—personal sphere transitions	
"My cCHALLENGE **was about to spend 1 h outside everyday**. This helped me in realising that it was winter time. I was sitting on a bench for 1 h to read a book and after a short time I had to put on gloves because my hands were frozen. I'm not used to staying 1 consecutive hour outdoors (plus sitting) during the winter and this also made me understand the impact that the temperature of the environment has on our habits. I also realised how much we no longer pay attention to natural rhythms ***[B]***. I had to decide what time to be outside and I realised that the sun was setting early and that if I went out when the sun had set it was more difficult to resist. I had to somehow synchronise with the rhythms of nature. This made me notice how in our comfort zone, we are no longer used to observing and synchronising with the rhythms of nature. **This "natural obstacle" to my cCHALLENGE led me to revise some of my habits. Usually after lunch I would relax on the sofa watching television. Now, since the time slot after lunch is the hottest time of the day, I go out for 1 h in the open air to complete my cCHALLENGE *[A]***. There are days when I don't feel like it, but I took this challenge as a commitment and I have to honestly say that after doing it I feel fine, even if I have simply been in the garden reading rather than taking a walk. I made more time for myself than I did before."—SM"	Sentence ***[A]*** is an example of how a change in the practical sphere can be characterised/recognised, indeed it is possible to identify: **presence of specific actions and/or behaviours that directly contribute to a desired outcome and that can be measured/monitored/evaluated**. Sentence ***[B]*** is an example of how a change in the practical sphere leverage a change in the personal sphere.
Practical sphere—political sphere transitions	
"Today I wanted to tell you about two **Apps that I discovered lately, that I found very useful and are also environmentally friendly**. The first one is < < To good to go > >, an App that helps reduce food waste by connecting restaurants and cafe with costumers that are willing to buy the unsold food of the day at a very cheap price, food that otherwise would be thrown away! The second one is < < Cortilia > >, it is an online groceries store that sells only food that's biological and comes from nearby farmers. With this App I can have delicious, seasonal fruits and vegetables every week without having to buy them! **They are app that re now used in a systematic way and I'm supporting their use in the context of my school. Those Apps are a nice example of an institutional change since an informatic engineer turned a good practice into a structural app that can be downloaded and used in a systematic way by restaurants, bar and by the people *[A]***. A good practice, maybe adopted some years ago from few people, has been turned now into a collective systematic way to recycle the food in a city ***[B]***. I think we need more innovation like this -SF"	Sentence ***[A]*** is an example of how a change in the political sphere can be characterised/recognised, indeed it is possible to identify: **presence of systems and structures that facilitate or constrain practical responses to sustainability and climate change; focus on a change that include collective and systemic actions**. Sentence ***[B]*** is an example of how a change in the political sphere leverage a change in the practical sphere.
Personal sphere—practical sphere transition	
"In my challenge I have chosen to reduce the consumption of meat. What makes it difficult is that my parents don't particularly agree with my choice but I have vegetarian friends who are supporting me, so I'm happy. To tell the truth, it doesn't seem like a particularly difficult choice to make, **my friends have lent me some books and reading them I inquired about how to have a balanced diet even reducing meat. I have made a food culture thanks to these books are not books by radical people. I liked them and they gave me a lot of confidence because they are books by university professors who are experts in nutritionists, all balanced people who made me find a way to approach a diet with little meat**. in the end it is not such a difficult challenge. —SF"	Sentence ***[A]*** is an example of how a change in the personal sphere can be characterised/recognised, indeed it is possible to identify: **presence of a dynamic between the "self" and the "others"; focus on results that can challenge assumptions, questioning beliefs, and exploring alternatives leads to more expansive and inclusive worldviews.** Sentence ***[A]*** is also an example of how a personal (cultural) interest leverage a change in the practical sphere.
Practical—political—personal sphere transitions	
"My challenge was **to reduce waste and, in particular, to reduce plastics**. In recent days I have tried to focus more on what is related to the visibility and sharing/advertising of this initiative. I shared the challenge immediately with family and, after a week, **we completely replaced the use of food-grade plastic film at home by purchasing re-usable wax materials. We found a service for glass-water distribution at home and we also convinced our neighbours to eliminate plastics by having glass water delivered to their home. At school now I always carry my canteen and I have also convinced my closest friends to do it *[A]***. After the first positive feedbacks from my family and my closest friends, others came in very contrasting ways. Some just do not share or do not feel close to them the "ecological cause" and others have shown themselves to be very suspicious and critical of the modalities of the project, including some of my teachers.	

(Continued)

TABLE 3 | (Continued)

Students' words	Example of possible markers for recognising belonging and/or transitions
But with a group of friends from the "Friday for future" movement **we went to the principal of the school, and we asked her to remove the plastic water bottles from the machines and to install water dispensers, we created a program in which we want to organise a fundraiser to finance the project *[B]***. To prepare our request, we also did a calculation of the impact this change could have—and it's huge! What I do not understand is how a scientific, tried and proven discourse that, among other things, concerns us all can still be viewed with suspicion or not perceived as real and tangible. My cCHALLENGE is going fine. but **I realised that it is not enough to change my habits, it takes something more and, starting from there, together with the others we can realise a more systemic and cultural change *[C]***—I need to believe it will be possible!—SM"	Sentences ***[A]***, ***[B]*** and ***[C]*** are examples of sentences that show features, respectively, belonging to practical, political and personal spheres. The whole argument developed by the student show the extent to which the CHALLENGE was able to foster an attitude of integration among all the three spheres and how the change, even starting from one sphere, can leverage other changes over the other spheres.

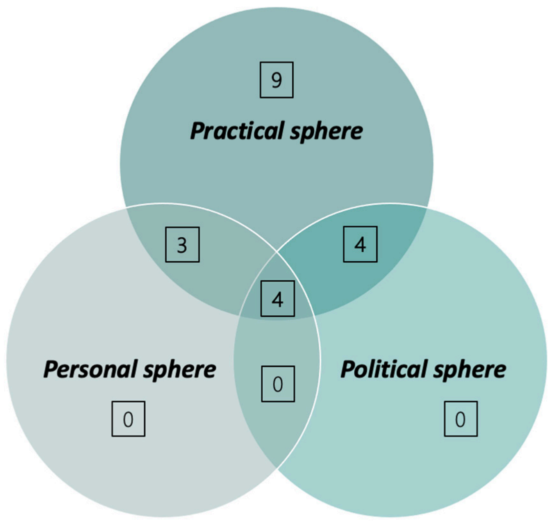

FIGURE 7 | Students' positioning across the three spheres.

spheres of transformation (practical, political, personal) and their relations in students' narratives.

Table 3 shows three exemplary excerpts that illustrate awareness with respect to change and the corresponding three spheres of transformation.

By applying the makers shown in the table, passing through the corpus of data, i.e., sentences coming from blogposts and collective discussions grouped per student, we were able to recognise in the students' responses to which of the three spheres they were mainly centred. **Figure 7** shows a graph representing how the students repositioned over the three spheres.

As for the type of reflection supported by the tool, the most frequent and widespread aspect was the development of a practical change or, at least, of the level of awareness with respect to the triggering of a change in practical habits and routines. The very evident aspect is that there are no students that refer only to either the political sphere or the personal one.

From this analysis, we can discuss the emergence of a transversal point, the belief that the challenge of sustainability is not only a process of behavioural transformation (*practical sphere*) but also of values and perspectives (*personal sphere*) that can be related to the change on a collective level played, for example, by decisions involving the policies of a country (*political sphere*).

Although everyone has reached a level of awareness of the importance of the issue at least in one of the sphere and more than half of them in a transition among two or three spheres, it was not so trivial to trigger a dynamic aspect (an understanding of the relationship) between the three spheres, which is not surprising given that the importance and significance ascribed to these spheres are prone to culturally validated world views, heuristics in human sense-making, and organised efforts to confuse the public on climate change that attributes what are systemic and political processes into individuals' responsibilities and tasks. However, an important finding in this article is that promising patterns were identified in section "Tracing the Change." In particular, a double shift in the reasoning was triggered:

(i) the interplay between making choices at the individual level in the cCHALLENGE and then at the community level in the C-ROADS by "virtually" experiencing the impacts of their choices in terms of climate change scenarios that involve them as community members in an authentic way, allowing the students to realise that taking any personal position in the face of climate data is a decision that has ethical implications and that holding on to *status quo* has implications for the dynamics between the climate and human society;

(ii) any action related, more or less explicitly, to the process of decision-making helped the students in realising that, in a complex dynamic system, the individual role can scale up at more systemic—and, hence, political—change and again scale down again on the individuals by having an impact at a level of personal/cultural aspects.

DISCUSSION

In this study, we analysed a pilot study where we used some tools related to climate change aimed at fostering a transformative dimension and activating an individual/collective dynamic as part of science learning/education.

The analysis of the closed-ended questions, used for building up the overall picture, showed several important characteristics in students' dealing with complex socio-scientific issues related to climate change. One of the most interesting results is that, when discussing climate change, the teaching design enabled students to ground their 30 days cCHALLENGE within the scientific discipline while making sense of its societal dimension. Indeed, although the perception of the urgency of the problem has taken a hold of the youth in the last years, we are still continuing to address and develop scientific literacy as a capacity to use and engage critically with science in decision-making and activism, which requires the development of teaching practices that enable to connect the complexity of CC with the disciplinary contents and how these are connected to socio-behavioural aspects. This first analysis revealed that students' conceptions of their own role as change-makers are contradictory, whereas, the students were able to see individuals as part of the problem, as they had more difficulties in seeing the individuals as part of the solution.

Although being part of the problem and being part of the solutions are two faces of the same coin, the second aspect requires a shift of perspective from a passive acceptance of a problem to a more agentic response that implies a deep cultural change. This issue emerged also from the analysis of the open-ended questions when we saw that the request to make choices about climate negotiations is open toward students' recognition of the importance of assuming the risk and complexity of making decisions based on scientific knowledge.

The thematic analysis allowed us to go more in-depth with respect to this latter aspect. The analysis pointed out some interesting patterns that suggest some ways to trigger a dynamic relationship between the individual attitudes and the collective dimension:

(a) awareness of supporting climate change and sustainability challenge not merely by following good practice in personal everyday life but also by including the wealth of disciplinary knowledge on the subject;
(b) ability to recognise a plethora of different actors who may have different roles in addressing the climate problem, like, for example, the importance not only of the role of professional experts but of political decision-makers and citizens;
(c) recognition of the fact that inclusion of science-based decisions concerning SSI aspects that cannot be considered neutral from a value perspective.

The questionnaire data indicated a tendency for students to be more aware of individuals to cause climate change than to be part of the solution. We recognised that when the three elements, a-c, were present, the students were able to make a diverse shift that helped them to connect knowledge to agency. The analysis suggests that the characteristics of students' contextual connections in their sense-making processes are an important area of research to further explore the interconnections between complex sustainability challenges, scientific knowledge, and students' agency.

However, when we matched the data against the model of the three spheres of transformation, what emerged is that the agency still remains mainly at the level of the practical sphere and only in some cases did a deeper understanding of the dynamic between the practical, the political, and the personal emerge. This means that agency can be considered as stratified: developing a level of agentic attitude that nudge toward good sustainable behaviours should connect with a deeper layer of agency where changing behaviours is only the result of a deeper change in terms of cultural views, values, beliefs, motivations, etc. (O'Brien and Sygna, 2013).

CONCLUSION

In this study, we started from the idea that the current societal problems are urgently challenging science educators and, in particular, challenge us to re-think and re-analyse the role of teaching scientific literacy in schools in providing critical lenses to the students for becoming responsible citizens while considering their role as citizens within the complex global society.

Since 2018, the perception of the problem of climate change and sustainability challenges has changed profoundly. Young people took to the streets to express the urgency of a change of direction in global policies. Their request thundered toward the political and economic world but not exclusively. Faced with the lack of permeability of the school with respect to the urgency to open up to the real problems of society, the young people turned directly to the surrounding world. At the same time, the students took upon a complex challenge, immersed in a vast amount of information, ideas, discourses, values, and interests, part of the fabric of society. To teach students to successfully navigate and act in this mixture of a sense of urgency and complexity calls for sophisticated critical thinking abilities in order to assess the correctness, social relevance, and legitimacy of science so that they are transformed into knowledge and skills for social action (Jenkins, 1994). The educational institution is struggling with fulfilling its task of preparing young people for the challenges facing them and, within the SEAS project, we are asking ourselves what it means to equip school students with the knowledge, experience, and supportive structures they need to face the complexity of the world and contribute as individuals, citizens, and active participants to enable the transformation required by current societal challenges.

As it is stated by Tasquier and Pongiglione (2017), until some few years ago, the problem for the individuals was to recognise that climate change exists and that it has anthropogenic causes and to be part of it as individuals. As demonstrated from recent reports (European-Commission [EC], 2019; European Investment Bank, 2020), the actual problem lies on the other face of the coin, in the sense that now there is a more widespread awareness with respect to it, but what still needs to be recognised is the awareness that individuals need to be part of the solutions as they start to recognise their agency as practical action that connects a personal, political, and individual sphere. Indeed, even if the level of trustworthiness with respect to the importance and the urgency of climate change is highly increased, an obstacle still remains: the agentic role of individuals in terms of their possibility to influence the collective dimension and the evolution of the system. What is crucial in this obstacle is understanding how to trigger a sense of agency that allows learners to move from practical-centred worldviews of change toward deep transformational change across the personal and the political, structural levels. In addition, education for sustainability requires further exploration of ways to integrate historical and political causes as part of our socio-scientific understandings of climate change (Shove, 2009), supporting students to take informed committed stances on complex issues as political agents (Stetsenko, 2016a).

The combination of the tools examined in this study was shown to trigger an important dynamic. The request to make choices both in the cCHALLENGE and in the role-play simulation about climate negotiations opens toward the fact that personal, social, and affective values are inextricable from making decisions. In discussing the possible impacts of climate change-related to possible scenarios, the students realise the importance of assessing the risk of a decision because of the scientific evidence of anthropogenic climate change, showing that the climate system and humans are dynamically interacting in a human timescale in the Anthropocene, compared to the geologic time scale characterising the Holocene (Latour, 2017). This means that to not take any personal position is, more or less explicitly, a decision with practical consequences. A challenge for teaching is the lack of immediate and local consequences of individual action. Roleplay and simulation can support students in making the crucial connections between the personal and the systemic (political and cultural spheres). Despite the limitation of being a pilot, this study points out that the climate discourse implies the involvement and the opening of decision-making scenarios. For some students, new insights emerging from participating in such a scenario created a perceived capacity to drive change and engage in collaborations to promote change on a broader scale.

The tools examined in this study should not be considered as simple games but, as we argue, embed some important principles that have the potential to enhance science education in a context in which change-making is becoming increasingly important to be a literate citizen. School science is looking for the opportunity to address real-life problems, but despite progress made in inquiry-based teaching and SSI (Sadler et al., 2017), it still lacks principles and tools that are reasoned to embody SSI principles and activate social dynamics within, and thanks to the discipline, dynamics that allow the students to grow up as present and future citizens within the deep groove of the disciplines.

DATA AVAILABILITY STATEMENT

Raw data have been stored in a private folder and are not published open access.

ETHICS STATEMENT

This study was framed within the Horizon 2020 Research and Innovation Programme under grant agreement No 824522. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

GT designed the study, collected the data, led the analysis, and wrote the first version of the manuscript. EK and AJ contributed to the data analysis and the re-writing and revision of the manuscript. All authors contributed to the article and approved the submitted version.

FUNDING

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under (grant agreement no. 824522).

ACKNOWLEDGMENTS

The data discussed in this manuscript were collected by the Bologna research team coordinated by Prof. Olivia Levrini and have been analysed and processed by the authors of this manuscript. The use of cCHALLENGE and the data belonging to it were collected thanks to the collaboration with the cCHANGE team (partner of the SEAS project). The activity about climate negotiations was implemented in collaboration with Eleonora Cogo from CMCC.

REFERENCES

Anfara, V. A., Brown, K. M., and Mangione, T. L. (2002). Qualitative analysis on stage: Making the research process more public. *Educ. Res.* 31, 28–38. doi: 10.3102/0013189x031007028

Barelli, E., Branchetti, L., Tasquier, G., Albertazzi, L., and Levrini, O. (2018). Science of complex systems and citizenship skills: a pilot study with adult citizens. *Eurasia J. Math. Sci. Technol. Educ.* 14, 1533–1545. doi: 10.29333/ejmste/84841

Bengtsson, S., Jornet Gil, A., Van Poeck, K., and Knain, E. (2020). "D2.2 – Definitions of shared pool of concepts," in *Document delivered do the EC about SEAS project*, (SEAS).

Bentz, J., and O'Brien, K. (2019). ART FOR CHANGE: Transformative learning and youth empowerment in a changing climate. *Elementa* 7:52. doi: 10.1525/elementa.390

Bøe, M. V., Henriksen, E. K., Lyons, T., and Schreiner, C. (2011). Participation in science and technology: young people's achievement-related choices in late-modern societies. *Stud. Sci. Educ.* 47, 37–72. doi: 10.1080/03057267.2011.549621

Branchetti, L., Cutler, M., Laherto, A., Levrini, O., Palmgren, E. K., Tasquier, G., et al. (2018). The I SEE project: an approach to futurize STEM education. *Vis. Sustainab.* 9, 10–26.

Braun, V., and Clarke, V. (2006). Using thematic analysis in psychology. *Q. Res. Psychol.* 3, 77–101. doi: 10.1191/1478088706qp063oa

Braun, V., and Clarke, V. (2019). Reflecting on reflexive thematic analysis. *Q. Res. Sport Exerc. Health* 11, 589–597. doi: 10.1080/2159676X.2019.1628806

Byhring, A. K., and Knain, E. (2016). Intertextuality for handling complex environmental issues. *Res. Sci. Educ.* 46, 1–19. doi: 10.1007/s11165-014-9454-6

Charmaz, K. (2003). "Grounded theory: Objectivist and constructivist methods," in *Strategies for qualitative inquiry*, 2nd Edn, eds N. K. Denzin and Y. S. Lincoln (Thousand Oaks, CA: Sage), 249–291. doi: 10.1016/j.nedt.2006.09.001

Cobern, W. W., and Aikenhead, G. S. (1998). "Cultural Aspects of Learning Science," in *International Handbook of Science Education*, Vol. 2, eds B. J. Fraser and K. G. Tobin (Dortrecht: Kluwer Academic Publishers), 39–52. doi: 10.1007/978-94-011-4940-2_3

Dillon, J., and Avraamidou, L. (2020). Towards a Viable Response to COVID-19 from the Science Education Community. *J. Activ. Sci. Technol. Educ.* 11, 1–6. doi: 10.33137/jaste.v11i2.34531

Echeverri, J. F., and Sadler, T. D. (2011). Gaming as a Platform for the Development of Innovative Problem-Based Learning Opportunities. *Sci. Educ.* 20, 44–48.

Erduran, S. (2020). Science education in the era of a pandemic: how can history, philosophy and sociology of science contribute to education for understanding and solving the Covid-19 crisis? *Sci. Educ.* 29, 233–235. doi: 10.1007/s11191-020-00122-w

Erstad, O., Kumpulainen, K., Makitalo, A., Shrøder, K. C., Pruulmann-Vengerfeldt, P., and Jóhannsdóttir, T. (2016). "Tracing Learning Experiences within and across Contexts," in *Learning across Contexts in the Knowledge Society*, eds O. Erstad, K. Kumpulainen, K. C. Schrøder, P. Pruulmann-Vengerfeldt, and T. Jóhannsdóttir (Rotterdam: Sense Publishers), 1–13. doi: 10.1007/978-94-6300-414-5_1

European Investment Bank (2020). *The EIB climate survey 2019-2020. How citizens are confronting the climate crisis and what actions they expect from policymakers and businesses*. Luxembourg: European Investment Bank.

European Union (2015). *Science education for responsible citizenship*. Netherlands: European Union.

European-Commission [EC] (2019). *Special Eurobarometer 490: Climate Change. Survey requested by the European Commission, Directorate-General for Climate Action and co-ordinated by the Directorate- General for Communication*. Brussels: EC, doi: 10.2834/00469

Evagorou, and Nielsen (2019). "Socioscientific issues: Searching for new perspectives," in *Plenary Talk at the European Science Education Research Association Conference*, (Bologna: *ESERA*).

Glaser, B., and Strauss, A. (1967). *The discovery of grounded theory*. Hawthorne, NY: Aldine Publishing Company.

Hodson, D. (2003). Time for action: science education for an alternative future. *Internat. J. Sci. Educ.* 25, 645–670. doi: 10.1080/09500690305021

Hodson, D. (2010). Science education as a call to action. *Can. J. Sci. Math. Technol. Educ.* 10, 197–206. doi: 10.1080/14926156.2010.504478

Hodson, Ds. (2017). "Foreword: The significance of STEPWISE for fostering life-long sociopoligical activism," in *Science and technology education promoting wellbeing for individuals, societies and environments*, ed. L. Bencze (New York, NY: Springer International Publishing), doi: 10.1007/978-3-319-55505-8_1

Hoffman, A. J. (2015). *How Culture Shapes the Climate Change Debate*. Stanford: Stanford University Press.

Hulme, M. (2015). (Still) disagreeing about climate change: which way forward? *Zygon§* 50, 893–905. doi: 10.1111/zygo.12212

IPCC (2021). *Climate change 2021: The physical science basis. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change*. Cambridge, MA: Cambridge University Press.

Jenkins, E. W. (1994). Public understanding of science and science education for action. *J. Curr. Stud.* 26, 601–611. doi: 10.1080/0022027940260602

Kajama, A., and Kumpulainen, K. (2019). Agency in the making:Analyzing students' transformative agency in a school-based makerspace. *Mind Cult. Activ.* 26, 266–281. doi: 10.1080/10749039.2019.1647547

Knain, E., and Odegaard, M. (2018). "The Implementation of Scientific Literacy as Basic Skills in Norway After the School Reform of 2006," in *Global Developments in Literacy Research for Science Education*, Chap. 2, eds Tang K-S and K. Danielsson (New York, NY: Springer), 15–28. doi: 10.1007/978-3-319-69197-8_2

Kolstø, S. D. (2001). Scientific literacy for citizenship: tools for dealing with the science dimension of controversial socioscientific issues. *Sci. Educ.* 90, 632–655.

Latour, B. (2017). *Facing Gaia: Eight Lectures on the New Climate Regime,* Kindle Edn. Cambridge: Polity Press.

Leu, D. J., Slomp, D., Zawilinksi, L., and Corrigan, J. A. (2016). "Writing Research trough a New Literacies Lens," in *Handbook of Writing Research. 2. Edition*, eds C. A. MachArthur, S. Graham, and J. Fitzgerald (New York, NY: The Guilford Press), 41–53.

Levinson, R. (2006). Towards a theoretical framework for teaching controversial socio-scientific issues. *Internat. J. Sci. Educ.* 28, 1201–1224. doi: 10.1080/09500690600560753

Levinson, R. (2007). Promoting the role of the personal narrative in teaching controversial socio-scientific issues. *Sci. Educ.* 17, 855–871. doi: 10.1007/s11191-007-9076-8

Levrini, O., Fantini, P., Barelli, E., Branchetti, L., Satanassi, S., and Tasquier, G. (2020). The present shock and time te-appropriation in the pandemic era: Missed opportunities for science education. *Sci. Educ.* 2020:159. doi: 10.1007/s11191-020-00159-x

Levrini, O., Tasquier, G., Barelli, E., Laherto, A., Palmgren, E., Branchetti, L., et al. (2021). Recognition and operationalization of Future-Scaffolding Skills: results from an empirical study of a teaching–learning module on climate change and futures thinking. *Sci. Educ.* 105, 281–308. doi: 10.1002/sce.21612

Levrini, O., Tasquier, G., Branchetti, L., and Barelli, E. (2019). Developing future-scaffolding skills through science education. *Internat. J. Sci. Educ.* 41, 2647–2674. doi: 10.1080/09500693.2019.1693080

McGrath, M. (2021). Climate change: IPCC report is 'code red for humanity'. *BBC News* 2021:58130705.

Nielsen, J. A. (2012). Science in discussions: an analysis of the use of science content in science content in socioscientific discussions. *Sci. Educ.* 96, 428–456. doi: 10.1002/sce.21001

Öhman, J. (2009). Climate change education in relation to selective traditions in environmental education. *South. Afr. J. Env. Educ.* 26, 49–57.

O'Brien, K., and Sygna, L. (2013). "Responding to Climate Change: The Three Spheres of Transformation," in *Proceedings of Transformation in a Changing Climate*, (Oslo: University of Oslo), 19–21.

Reiss, M. (2020). Science Education in the Light of COVID-10. *The Contribution of History, Philosophy and Sociology of Science*. *Sci. Educ.* 2020:5. doi: 10.1007/s11191-020-00143-5

Roth, W.-M., and Jornet, A. (2014). Towards a theory of experience. *Sci. Educ.* 98, 106–126. doi: 10.1002/sce.21085

Roth, W.-M., and Jornet, A. (2017). *Understanding educational psychology. A late Vygotskian, Spinozist approach*. New York, NY: Springer. doi: 10.1007/978-3-319-39868-6

Roth, W.-M., and Lee, Y. J. (2007). Vygotsky's neglected legacy: cultural-historical activity theory. *Rev. Educ. Res.* 77, 186–232. doi: 10.3102/0034654306298273

Sadler, T. D. (2009). Situated learning in science education: socio-scientific issues as contexts for practice. *Stud. Sci. Educ.* 45, 1–42. doi: 10.1080/03057260802681839

Sadler, T. D., Foulk, J. A., and Friedrichsen, P. J. (2017). Evolution of a model for socio-scientific issue teaching and learning. *Internat. J. Educ. Math. Sci. Technol.* 5, 75–87. doi: 10.18404/ijemst.55999

Sadler, T. D., and Zeidler, D. (2005). Patterns of informal reasoning in the context of socioscientific decision making. *J. Res. Sci. Teach.* 42, 112–138. doi: 10.1002/tea.20042

Schreiner, C., Henriksen, E. K., and Hansen, P. J. K. (2005). Climate Education: empowering Today's Youth to Meet Tomorrow's Challenges. *Stud. Sci. Educ.* 41, 3–50. doi: 10.1080/03057260508560213

Shove, E. (2009). Beyond the ABC: climate change policy and theories of social change. *Environ. Plan.* 42, 1273–1285. doi: 10.1068/a42282

Solli, A. (2019). Appeals to Science: Recirculation of Online Claims in Socioscientific Reasoning. *Res. Sci. Educ.* 2019:9878. doi: 10.1007/s11165-019-09878-w

Sterman, J., Franck, T., Fiddaman, T., Jones, A., McCauley, S., Rice, P., et al. (2015). WORLD CLIMATE: a Role-Play Simulation of Climate Negotiations. *Simul. Gam.* 46, 348–382. doi: 10.1371/journal.pone.0202877

Stetsenko, A. (2016a). *The transformative mind. Expanding Vygotsky's approach to development and education*. New York, NY: Cambridge University Press. doi: 10.1017/9780511843044

Stetsenko, A. (2016b). Moving beyond the relational worldview: Exploring the next steps premised on agency and a commitment to social change. *Hum. Dev.* 59, 283–289. doi: 10.1159/000452720

Tasquier, G. (2015). How does epistemological knowledge on modelling influence students' engagement in the issue of climate change? *Nuovo Cimento* 38C:112.

Tasquier, G., Branchetti, L., and Levrini, O. (2019). Frantic Standstill and Lack of Future: how Can Science Education Take Care of Students' Distopic Perceptions of Time? *Bridg. Res. Pract. Sci. Educ.* 2019, 205–224. doi: 10.1007/978-3-030-17219-0_13

Tasquier, G., Levrini, O., and Dillon, J. (2016). Exploring students' epistemological knowledge of models and modelling in science: results from a teaching/learning experience on climate change. *Internat. J. Sci. Educ.* 38, 539–563. doi: 10.1080/09500693.2016.1148828

Tasquier, G., and Pongiglione, F. (2017). The influence of causal knowledge on the willingness to change attitude towards climate change: results from an empirical study. *Internat. J. Sci. Educ.* 39, 1846–1868. doi: 10.1080/09500693.2017.1355078

Tidemand, S., and Nielsen, J. A. (2017). The role of socioscientific issues in biology teaching: from the perspective of teachers. *Internat. J. Sci. Educ.* 39, 1–18. doi: 10.14689/ejer.2017.72.4

Wiblom, J., Rundgren, C.-J., and Andrée, M. (2019). Developing Students' Critical Reasoning About Online Health Information: a Capabilities Approach. *Res. Sci. Educ.* 2017, 1759–1782. doi: 10.1007/s11165-017-9674-7

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.