CHAPTER 5

Future-Oriented Science Education Building Sustainability Competences: An Approach to the European *GreenComp* Framework

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Introduction

Responding to global sustainability crises is believed to require a fundamental rethinking of the values, purposes and methods of all education (Lotz-Sisitka et al., 2015; UNESCO, 2021). Education for Sustainable Development (UNESCO, 2017) implies holistic learning that aims to bring about transformation (Hodson, 2011). In the field of science education, demands for a societal change have induced the emergence of a

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radical and critical orientation labelled "Vision III" of science education (Sjöström et al., 2017). According to this vision, it is no longer enough that students learn scientific concepts (Vision I) or how to apply them in real-life contexts (Vision II) (see Roberts & Bybee, 2014). Science education must also directly support value-based transformative agency in both individuals and society (European Commission, 2020a).

Wide sociopolitical interest in science education is due to the constantly growing role of science and technology in everyday life and social decision-making in contemporary societies, including issues related to sustainability crises. Additionally, several structural inequality problems concern science and technology (see e.g., Felt et al., 2016). For these reasons, the European Union has, for some time, noted the potential of science education in promoting responsibility and sustainability. These aspects have been central in European recommendations on science education (European Commission, 2015; Rocard et al., 2007) and initiatives to bring the idea of Responsible Research and Innovation (RRI) to schools (Laherto et al., 2018). The latest guidance document that is likely to have a considerable influence on European science education curricula and pedagogies is the *GreenComp* framework (Bianchi et al., 2022) launched in 2022. This framework proposes a set of sustainability competences that should be cultivated across all education due to global ecological crises.

In this chapter, we discuss the potential of science education for addressing the sustainability competences defined in *GreenComp*. We first review how each *GreenComp* competence area is currently addressed in science education research and practice, and then we argue for the Future-Oriented Science Education (FOSE) approach as effectively connecting all these competence areas. We provide examples from the EU-funded project "FEDORA" (https://www.fedora-project.eu/). We conclude by discussing the potential of science education in addressing the global sustainability crises.

The *GreenComp* Framework

Background and Aim

GreenComp (Bianchi et al., 2022) is the European Sustainability Competence Framework, developed by the Joint Research Center of the European Commission. This competence framework has been written following the policy initiatives issued by the European community in previous years, in particular, the "European Green Deal" (European Commission, 2019), the "European Skills Agenda for Sustainable Competitiveness, Social Fairness and Resilience" (European Commission, 2020a), the EU biodiversity strategy for 2030 "Bringing Nature Back into our Lives" (European Commission, 2020b), and "Achieving the European Education Area by 2025" (European Commission, 2020c). All these official documents state the need to develop a common framework for sustainability and the importance of education and training for becoming a climate-neutral continent by 2025.

The authors of *GreenComp* worked closely with experts and stakeholders using a mixed-method research process and followed the general methodology developed, tested, and validated by the Joint Research Center to create several competence frameworks, including *DigComp 2.2* (Vuorikari et al., 2022), *EntreComp* (Bacigalupo et al., 2016) and *LifeComp* (Sala et al., 2020).

The aim of *GreenComp* is "to foster a sustainability mindset by helping users develop the knowledge, skills and attitudes to think, plan and act with empathy, responsibility, and care for our planet" (Bianchi et al., 2022, p. 2). It provides a wide reference framework for designing activities whose aim is to develop sustainability competences and for assessing progress in supporting education and training for sustainability that can be used by all those involved in lifelong learning. The *GreenComp* framework aims to generate a common starting point for learners and educators when thinking about how sustainability can be formulated as competences. In the framework, *sustainability* is defined as "prioritising the needs of all life forms and of the planet by ensuring that human activity does not exceed planetary boundaries" (p. 12). The sustainability competence defined by *GreenComp* unfolds into a set of sub-elements that the authors refer to as competences for sustainability. The goal of these competences is to generate action and new visions for our future, thereby empowering learners to not reject complexity and to apply choices based on sustainability values. The *GreenComp* framework refers to the foundations of sustainability education through the term "learning for environmental sustainability", which is defined as the "aim to nurture a sustainability mindset from childhood to adulthood with the understanding that humans are part of and depend on nature" (p. 13).

Competence Areas

GreenComp is divided into 4 competence areas, each subdivided into 3 competences. Taken together, these 12 competences reconstruct the definition of sustainability from the perspective of objectives, needs and demands. The four areas with their respective competences are 'Embodying sustainability values' (Valuing sustainability, Supporting fairness, Promoting nature); 'Embracing complexity in sustainability' (Systems thinking, Critical thinking, Problem framing); 'Envisioning sustainable futures' (Futures literacy, Adaptability, Exploratory thinking); and 'Acting for sustainability' (Political agency, Collective action, Individual initiative). The four areas can also be described as follows:

> 'Embodying sustainability values' prompts reflection on the personal values and related biases we hold as members of society, and supporting principles of fairness and justice for present and future generations, based on which a more sustainable future for society can be built.
>
> 'Embracing complexity in sustainability' aims to enable a systemic view of problems related to our society and unsustainability, helping to identify connections and feedback loops within systems and to address problems from a sustainable point of view. The relation between environmental issues and income inequality is an example of this.
>
> 'Envisioning sustainable futures' emphasizes the importance of being able to think about the future in terms of possibilities to imagine possible scenarios for which actions can be taken today. Thinking about the future can mean imagining a better world from the point of view of sustainability. This involves recognising inherent uncertainty, accepting the impossibility of predicting what will happen, the skill of identifying probable, alternative and preferred futures, and the need to influence and shape our circumstances to achieve one of these preferred futures.
>
> 'Acting for sustainability' focuses on the roles of individuals and collectives in terms of real actions aimed at reaching sustainability goals. Acting to change stakeholders' and legislators' priorities must be promoted as a necessary activity to shape the future. Individual actions from voting and volunteering to career and consumer choices should be recognized, as should collective cultural, social and policy changes.

Interconnectedness of the Competence Areas

The authors of the *GreenComp* framework consider the 12 competences as "interrelated and interconnected and should be treated as parts of a whole […] *GreenComp* implies that sustainability as a competence is made of 12 building blocks" (p. 15). As a metaphor for this interrelation, the framework presents the image of bee pollination, where bees represent the competences related to the area 'acting for sustainability', flowers the area 'envisioning sustainable futures', the beehive the area 'embodying sustainability values' and pollen and nectar the area 'embracing complexity in sustainability'. The purpose of this visualization is to show the interdependencies of the 12 competences in the sense that they are fundamental to ensuring the survival of the whole ecosystem in its entirety.

The framework also offers two fictional use cases where the authors show how the 12 competences are interrelated and equally important. The first one describes a school teacher who starts changing her community through daily actions based on the 12 competences in order to restore and improve the environmental situation of a river close to her school where she brings her pupils. The second is about a young high school student and his willingness to change and improve his area by proposing competence-based educational activities aimed at reducing waste production to his schoolmates and teachers. These two cases, connected to real-life situations, show that the application of competences is quite natural if we reframe everyday problems from a sustainable perspective.

While the bee pollination metaphor highlights the interconnectedness of the competence areas and suggests some useful, even practical notions (e.g., that 'envisioning sustainable futures' contributes to 'embodying sustainability values' similarly to how flowers contribute to a beehive), we argue that further examples would contribute to providing increasingly robust practical indications on how the competence areas interlink in an educational context. Thusfar, in this chapter, we addressed the *GreenComp* framework on a more contextualized level, i.e., the level of curricular and pedagogical ideas and emphases. We aim to not only use the *GreenComp* competence areas as a framework to tackle issues in science education but also to explore the question of how the competence areas may interact in practice.

GreenComp Competences in Science Education Research and Practice

While *GreenComp* is a novel proposition, the framework builds on ideas that have previously been discussed and implemented in educational policymaking, curricular research, and teaching practice. The competences listed in *GreenComp* are not novel to science education either. In this section, we present some examples of how each *GreenComp* competence area has been addressed in science education research and practice.

'Embodying Sustainability Values' in Science Education

It is currently quite indisputable that values discussion is a central element of Education for Sustainable Development, environmental education, or climate education (e.g., Cantell et al., 2019). Yet, science lessons in school have usually not been considered as opportunities for values discussion. Rather, science teachers have avoided addressing value-laden issues or other matters of opinion to cherish a conception of science as objective and neutral. Such a view has been quite persistent in science education although philosophers and sociologists of science have, for a long time, highlighted the nature of science as a human endeavour led by human intentions and values (e.g., Irzik & Nola, 2011).

However, a number of movements in the field have taken steps forwards from the traditional emphasis on the epistemic and cognitive aspects of science and advocated dialogue on social values to both research and practice in science education. For example, approaches building on Socio-Scientific Issues (SSI) (e.g., Zeidler, 2014) typically address the values underlying decisions related to science and technology (e.g., Christenson et al., 2012). Similarly, contemporary conceptualizations of the Nature of Science (NoS) for science education depict science as not only a cognitive-epistemic but also a social-institutional system (Erduran & Dagher, 2014), embedding social values as inherent components of science. In other words, the scientific enterprise embodies various social values including social utility, respecting the environment, freedom, decentralizing power, honesty, addressing human needs, and equality of intellectual authority. Devoid of such values, it is difficult to imagine how science can play a positive role in society. Such conceptualization of NoS also aligns with the EU's concept of Responsible Research and Innovation (Laherto et al., 2018) and related political recommendations for science education

(European Commission, 2015). However, many science curricula (see e.g., Caramaschi et al., 2022; Kaya & Erduran, 2016) and textbooks (see e.g., McDonald, 2017) around the world neglect such social values embedded in NoS with very few exceptions (e.g., Mork et al., 2022).

Yet, the debate is ongoing about the appropriate way to incorporate values discussions in science lessons, especially when teaching value-laden content such as environmental sustainability. On the one hand, education aimed at predefined ethical conclusions implies indoctrination. On the other hand, teachers' values influence their teaching in any case, so there cannot be a 'neutral' position (Cotton et al., 2013). Pluralistic education aims to avoid these problems by considering values as a means of education rather than a normative aim (Sund & Öhman, 2014).

During the past decade, Vision III of scientific literacy (Sjöström et al., 2017), aiming to facilitate students' agency and transformative learning, has foregrounded values discussions in science education. Transformative and transgressive learning imply a deep reflection of one's own values as well as the social, cultural, political, philosophical, and economic structures that shape science and society (Lotz-Sisitka et al., 2015). The number of such initiatives and publications is growing in science education research, but it is not currently mainstream.

'Embracing Complexity' in Science Education

The science of complex systems is a technical area of scientific research that has received increasing attention because of its applications in socially relevant themes. The Nobel Prize in Physics 2021, given jointly to Manabe & Hasselmann and Parisi, was awarded "for groundbreaking contributions to our understanding of complex physical systems", which provided rigorous scientific foundations to our "understanding of Earth's climate (https://www.nobelprize.org/prizes/physics/2021). In addition to atmospheric physics, geophysics and climate science, the science (physics) of complex systems is at the basis of many other fields, such as epidemiology, biophysics and econophysics. Its conceptual and epistemological relevance has made it an interesting field for science education since the 1990s. The basic concepts of the science of complex systems have been educationally reconstructed for school teaching (Duit et al., 1997; Komorek et al., 2003) or used for analyzing and interpreting complex learning or teaching dynamics (Bloom & Volk, 2007; Jacobson et al., 2019). The educational relevance and "learnability" of the basic concepts have been investigated by several studies (e.g., diSessa, 2014; Duit & Komorek, 1997; Jacobson & Wilensky, 2006; Stavrou & Duit, 2014; Wilensky & Resnick, 1999).

At the core of these educational applications are concepts such as the definition of a complex system, the concepts of nonlinearity, deterministic chaos, high sensitivity to initial conditions (better known as the 'butterfly effect', Lorenz, 1972), feedback and self-organization (emergent properties). They are all key concepts for applying the science of complex systems to the social sciences (Turner & Baker, 2019).

All these concepts concur to problematize and revise the reductionist paradigm typical of Newtonian physics: in complex systems, understanding the individual components is crucial, but the knowledge of the parts is not sufficient to explain the behaviour of the whole system; the nonlinear interactions between single parts produce structures that, despite their material basis in the underlying components, can be conceptualized, in most cases, independently from the parts.

These aspects, together with the inner dynamics of nonlinear systems, paved the way to ground a new epistemology (Morin, 1986, 2001) in which Newtonian determinism, predictability, and linear causality are replaced by new forms of causality and new time structures, centred on concepts such as feedback loops and circular causality, which in turn emphasize possible future scenarios and future projections instead of future predictions. This new epistemology has been argued to have great potential to provide thinking skills to navigate our fast-changing society (Barelli et al., 2018; Cilliers, 2007; Morin, 2001), which is also at the basis of the current reports of the IPCC and of Futures Studies (Levrini et al., 2019).

All these studies in science education can contribute to making the principle of 'Embracing complexity in sustainability' a set of pragmatic educational goals through which students can be guided to develop systemic, multi-layered, nonlinear views to look at environmental issues and develop future scaffolding skills (Barelli, 2022; Levrini et al., 2019).

'Acting for Sustainability' in Science Education

While SSIs (socioscientific issues) have been on the agenda of science education research and practice for decades (Bencze et al., 2020; Zeidler, 2014) and typical SSIs often involve sustainability issues, SSI approaches usually focus on increasing the relevance of science education and/or facilitating societal debate and informed decision-making rather than facilitating students' practical action for change. The SSI approaches to science education have also been criticized as being too superficial and politically naive to catalyse societal change (Hodson, 2003, 2011; Sjöström et al., 2017). The more value-based and political idea of 'science education for action' (Hodson, 2003) has gained more ground only during the past decade through the growing realization of the importance of education in the global endeavour towards the United Nations' Sustainable Development Goals. UNESCO (2017, 2021) calls for action-based pedagogies that aim to bring about change not only in the learner but also in society. Similarly, Vision III of scientific literacy (Sjöström et al., 2017; see also Hodson, 2020) suggests that it is not sufficient to learn scientific concepts or how to apply them in real life contexts; science education must also directly support value-based, transformative agency.

While Vision III is still far from the mainstream of science education research and practice, there is an increasing number of initiatives and publications taking an action-centred perspective. Science education has been (re)purposed, for example, for facilitating participation in local communities (Roth & Lee, 2004) and broader democratic processes (Levinson, 2010) and for transforming oppressive conditions in society (Dos Santos, 2009). The action competence approach (Mogensen & Schnack, 2010), originally used mostly in Nordic countries for democratic, environmental and sustainability education, has been employed to some extent in science classrooms (e.g., Levrini et al., 2021; Rasa et al., 2022). The potential of science education in sociopolitical activism (see Bencze et al., 2012, 2020; Hodson, 2020) is increasingly recognized (see Journal for Activist Science & Technology Education, https://jps.library.utoronto.ca/index.php/jaste/).

'Envisioning Sustainable Futures' in Science Education

The fourth competence area, 'envisioning sustainable futures', has received less attention than the other *GreenComp* areas in the field of science education. While arguments for futures thinking, including perspectives regarding SSIs in science education, quite often point out that science and scientific literacy are important for the future, the concept of "future" is often vague and does not acknowledge that futures thinking may play a part in science education. However, discussion around this issue has clearly been emerging. For example, Lloyd and Wallace (2004) fleshed out an explicit argument for applying more general notions about futures in education in the field of science education and noted that "instruction and practice is needed in helping students to construct more useful and empowering images of possible futures" (p. 153). This and related arguments have been gradually building momentum, e.g., Hodson's (Hodson, 2011) overview of various perspectives on dealing with envisioned futures (such as the need to embrace and deal with complexity), Schreiner et al.'s (Schreiner et al., 2005) treatise of combating pessimism in empowering climate education, and Carter and Smith's (Carter & Smith, 2003) critique of the lack of futures perspectives and planetary perspectives in science education.

Such arguments often take the stance that science education should adopt ideas from the field of Futures Studies (e.g., Bishop et al., 2007; Kousa, 2011), and in fact some more recent initiatives have rather fully embraced this suggestion. For example, a key goal of the European Erasmus+ project "I SEE" (www.iseeproject.eu), a project to "futurize STEM education" (Branchetti et al., 2018), was to "support students in imagining a future for the world and for themselves" (p. 10). Furthermore, recent studies have explored how students' images of the future interrelate science and technology with sustainability (e.g., Rasa & Laherto, 2022).

Future-Oriented Science Education (FOSE)

FOSE Connecting the **GreenComp** *Competence Areas*

As our examples in the previous section show, there are various pedagogies and trends in science education that have or aim to contribute to the promotion of the *GreenComp* competence areas. However, many approaches to competences in science education research tend to be somewhat reductionist; most of the initiatives and publications we have referred to only deal with one or two of the *GreenComp* areas. We argue that in such approaches, there is an untapped potential for synergies between the competences. For example, students' agency facilitated through the action competence approach (see Section "'Acting for Sustainability' in Science Education") can be hindered if there is no explicit focus on value discussions (Section "'Embodying Sustainability Values' in Science Education"), complexity (Section "'Embracing Complexity' in Science Education") and envisioning desirable futures (Section "'Envisioning Sustainable Futures' in Science Education"). Science education could find more coherent approaches to sustainability education by interconnecting all four *GreenComp* areas. To provide an example of such coherence, in this section, we will discuss how *Future-oriented Science Education (FOSE)*, a somewhat recent approach, incorporates the four domains.

The FOSE approach is oriented towards Vision III of science education and draws on the fields of Futures Studies (e.g., Bishop et al., 2007; Kousa, 2011) and Futures Education. The FOSE approach has been developed within two EU-funded projects, "I SEE" (Branchetti et al., 2018; Levrini et al., 2021; Rasa et al., 2022) and "FEDORA" (Barelli et al., 2022; Laherto & Rasa, 2022; Rasa & Laherto, 2022; Rasa et al., 2023).

First and least surprisingly, *envisioning futures* is at the centre of FOSE. In typical future-oriented science pedagogies, students participate in formulating and examining various scenarios about possible, plausible, and preferable futures (e.g., Börjeson et al., 2006). Here, plausible futures may be used to construct pathways between the present moment and otherwise unforeseen risks or desirable (e.g., sustainable) futures and students' and general human agency (cf. Varpanen et al., 2022). Such scenario-thinking activities are particularly well-suited for science education since science and technology play major roles in (young) people's images of the future and their expectations, fears and ideals (Angheloiu et al., 2020; Cook, 2016; Kiilakoski, 2021). The concerns, fears and hopes are typically related to sustainability issues (e.g., Cook, 2016). In what follows, we argue that this core working method in FOSE, discussing *different futures* with considerations of science and technology, serves as a hub interlinking all *GreenComp* areas efficiently in a scientific context.

Relatedly, as FOSE has adopted the concept of "plurality" of futures (i.e., that a future is an idea that guides thinking and action), values are integrated into future-oriented science pedagogies on various levels. For example, studies have explored students' views of the desirability of emerging technologies (Rasa & Laherto, 2022) as well as how students conceptualize the value-based public discourse around such technologies (Rasa et al., 2023). We argue that discussing different future scenarios, including *desirable* futures, provides a fruitful context for value discussions—not only for 'embodying sustainability values' but also for negotiating, understanding and criticizing different values underlying the choices made in societal development.

The FOSE method of discussing different futures not only interlinks the competence areas 'envisioning sustainable futures' and 'embodying sustainability values' but also 'embracing complexity in sustainability'. This is because in FOSE, students not only *imagine* different futures but also generate them by studying sustainability issues in the context of a complex society with a variety of aspects, stakeholders, and interests. This is done, for example, through a 'backcasting' activity, where students are challenged to map a way to their desirable future by discussing complexity, using leverage points to affect the discussed system, and reconciling a variety of perspectives. While science and technology play important roles in the different futures created in FOSE, sustainability issues can never simply be solved (in a desirable future) only through science and technology. Rather, the future is seen as an inherently complex, acknowledging sustainability issues as "wicked problems". A constructed desirable future in FOSE can therefore act as both a "dream future" (embodying values and questioning limitations) and, even at the same time, a complex and problematised future where problems are solved through systemic change, trade-offs, and compromises. Specifically, in FOSE these perspectives are tied in with sociotechnoscientific issues: for example, a desirable technological future may involve hopes of human ingenuity overcoming climate change by geoengineering (Rasa & Laherto, 2022), while another desirable future highlights the responsible use of artificial intelligence (Rasa et al., 2023).

Finally, the *different futures* approach in FOSE ties together future imagination, values, and complexity and explicitly facilitates 'acting for sustainability'. First, "humans can only work to build a future if they can first imagine it" (Ellyard, as cited in Jones et al., 2012). Additionally, our experiences in FOSE have shown that during the courses students learn to consider the openness of the future not as a reason for anxiety but rather as an opportunity for agency (Rasa et al., 2022): one can only influence an uncertain future. However, FOSE also builds agency more explicitly: as argued above, FOSE is not only about imagining a sustainable future. In the backcasting activity, students figure out a way (a set of actions) to that future. In the FOSE modules developed in the "I SEE" and "FEDORA" projects, students typically build teams of 3–6, and each student has a specific professional or civic role in creating the future. In collaboration they figure out what kind of (science and technology related) expertise and collaboration they need in order to take the actions and overcome the obstacles to end up in the desirable future in which their chosen sustainability issue is solved. The backcasting activity ends with a consideration of what "was" the first step action they took at the start of their journey, that is, in the present day. According to feedback, students have found this aspect of FOSE courses particularly empowering for action (Branchetti et al., 2018; Levrini et al., 2021; Rasa et al., 2022).

Here, we have argued how the FOSE working method of discussing different futures effectively ties together all competence areas defined in the *GreenComp* framework. To further illustrate the idea, in the following, we give a few examples of FOSE activities developed in "FEDORA".

Examples of FOSE

In the "FEDORA" project, we implemented FOSE in secondary school science classrooms in Italy, Finland and the United Kingdom. Here, we showcase some examples to illustrate the ideas presented in the previous section on how the approach connects the competence areas.

The module developed by the University of Helsinki in collaboration with the Helsinki School of Natural Sciences (an upper secondary school with a science focus) engaged students in creating a sustainable future for the city of Helsinki. This experimental science course, titled "My city of the future", began with an introduction into futures thinking; how it often fails to predict the future, yet one can improve and systematize one's visions by distinguishing between thinking about possible, probable, and desirable futures. Over the duration of the course, students worked on their visions for Helsinki in 2050, writing evocative future descriptions in small groups. The texts were continually challenged by the teachers as well as three invited consulting experts (smart city anthropology, values in futures thinking, energy and sustainability transitions). The students also built timelines between today and their vision, mapping central actions to take to reach their desired future, paying special attention to systemic perspectives and the role of science and technology in creating sustainability (e.g., energy production) and shaping the city of the future (e.g., new technologies). Then, the students familiarized themselves with the publicly available "Carbon Neutral Helsinki 2035 Action Plan", guided by a pedagogical workshop on analysing values and assumptions in future scenarios, after which they met with one of the Action Plan's authors to discuss the rationale for the environmental policies of the city of Helsinki. During these activities, students compared their own thinking with official policies and contrasted the actions they wished to see taken with those currently planned or executed. Finally, guided by the teachers of the course, the students collected their own visions in a small pamphlet. The course ended with a discussion panel between our students, the head of the Helsinki City Climate Team and other students from the school in the audience during which we handed the finalized pamphlet over to the city.

The implementation in Oxford, UK, took place at the Natural History Museum involving Year 12 (16-year-old) students from Oxfordshire. The workshop was repeated three times and had three primary aims: (a) to familiarize with the causes and effects of climate change, (b) to discuss possible and desirable future scenarios regarding climate change, and (c) to become aware of the importance of personal choices and attitudes that have an impact on climate change. The session started with introductions and the administration of a questionnaire aimed at collecting data on students' views about climate change. Subsequently, a discussion was carried out guided by the key question of "*What is climate change?*" This question was unpacked through further questions such as "*How does what happens now differ from what happened in the past, and why? Are the changes desirable? What are the underlying causes for these changes?*" and "*How might climate change affect the future?*" Next, a group activity took place where the positive and troubled future scenarios were considered. The students prepared presentations, and the final plenary discussion was guided by students' anticipation of future scenarios about climate change. Through the various activities carried out in the workshop, the competence areas were promoted. For instance, the discussions around the differences in climate encouraged 'embracing complexity in sustainability', and the theme about the influence of climate change on the future was related to competence in 'envisioning sustainable futures'. Through the discussion questions, all competences were integrated into students' discussion, promoting not only knowledge of sustainability but also values and actions about sustainability.

The implementations in Bologna were a follow-up of empirical studies carried out in the previous project "I SEE". Modules with secondary school students have been realized not only on climate change but also on themes such as simulations of complex systems, artificial intelligence, and quantum technologies. They all include activities to enter the conceptual core of the theme, activities on the basic ideas of the science of complex systems and, finally, activities on foresight and backcasting. The crucial point in the design is that science (Physics, in particular) can be a source of knowledge, skills and attitudes that, if the contents are properly reconstructed, can be turned into competences that are clustered and valued in *GreenComp* (Levrini et al., 2019).

Empirical research on the influence of these FOSE implementations on students' thinking is currently underway in the last year of the "FEDORA" project. Tentative findings imply that the FOSE approach has been highly valued among students and seems to contribute to students' agency, systemic understanding, futures thinking and value discussion in the context of local and global sustainability issues. Earlier modules, developed in the "I SEE" project with similar orientation, have proven to influence students' perception of the future: from far and unimaginable, the future became conceivable as a set of possibilities, addressable through concrete actions and within their reach, in the sense that they became able to view themselves as agents of their own future (Levrini et al., 2021; Rasa et al., 2022). The earlier results also show that students developed 'future-scaffolding skills', skills that enable people to construct visions of the future that support possible ways of acting in the present with one's eye on the horizon (Levrini et al., 2021).

Discussion

In this chapter, we have first pointed out how each *GreenComp* competence area is currently addressed in different branches of science education research and practice. We have also argued that a more coherent and dynamic approach is needed to utilize the synergies between the competence areas and effectively support the action-taking and transformations required by the global ecological crises. We propose that the Future-Oriented Science Education (FOSE) approach, developed and tested in the "FEDORA" project, offers such an approach to orient science teaching and learning towards the sustainability competences defined in *GreenComp*. In the FOSE approach, students learn to envision sustainable futures and take action toward them by understanding the complexity of science-technology-society-environment relations and negotiating values underlying societal and technological development.

Our aim of integrating the *GreenComp* competence areas into a coherent approach finds support in earlier and current research addressing models of change and the transformative potential of educational actions for scientific literacy. For example, models of open schooling for sustainability, developed in science education (Tasquier et al., 2022), implement the heuristic model of the three spheres of transformation (O'Brien & Sygna, 2013) to frame the need to keep together values with the individual, collective, and political dimensions of agency. According to this model, a change for sustainability must interconnect three spheres: the practical sphere linked to individual behaviours, the political sphere linked to institutional and system aspects, and the personal sphere linked to values and worldviews. The practical sphere includes technical and behavioural changes, but it needs to be connected with sustainable, coherent changes in the political sphere. This sphere highlights the systems and structures that facilitate or impede transformations in the practical sphere and includes the social norms, rules, regulations, institutions, and infrastructure that define how society is organized. The political and practical spheres in turn are influenced by the inter-personal sphere involving individual and collective worldviews, values, beliefs, and paradigms that are at stake and that drive people's motives for practical and political action. This model has been implemented in the Horizon 2020 project "SEAS" (Tasquier et al., 2022), and it represents an important reference for "FEDORA". For *GreenComp*, the modules implemented by the open schooling networks in these projects can offer examples of how to keep together the three dimensions of 'Acting for sustainability' and show how the coherence and interconnection between institutional, collective, and individual spheres are fundamental. Furthermore, the implementation of the three spheres of changes in the modules shows to what extent 'Acting for sustainability' without 'Embodying sustainability values' risks weakening its transformative potential: a sense of agency limited to the practical or political sphere, without addressing and renegotiating values, does not foster a sustainable transformation (O'Brien & Sygna, 2013).

The second set of studies that support the need for a coherent picture concerns the investigation, in science education, of the "polarization attitude" that characterizes the reactions of the young (and the people in general) to the complexity of our society and its intrinsic uncertainty. The "polarization attitude" emerges when students, also in dealing with SSIs, tend to reduce the dynamics between two poles to its extremes by applying a binary system of positioning or evaluation (bad-good, certain-uncertain, in my reach-out of my reach, etc.) (Barelli et al., 2022). One manifestation of the polarization attitude concerns students' perceptions of the future known as "two-track thinking'. It refers to the tendency to see personal futures as positive and in one's own hands, while global futures are viewed as gloomy and out of one's influence (e.g., Cook, 2016; Rubin, 2013). Two-track thinking manifests itself in several types of polarization, e.g., between individual and collective dimensions or between career orientation and societal orientation.

Such research agendas contribute to the goal of promoting a new educational approach toward the complexity of wicked problems: education should keep together the three spheres of transformation and foster a new attitude to manage the tensions between different poles, avoiding polarized positioning. These are examples of perspectives to take on *GreenComp* to search for connections among the competence areas and within the areas and to find, in such nexuses, a new orientation for research in science education. After all, new ways of thinking—from imagining and working for fundamental sustainability transformations to adopting responsible long-term perspectives—are needed from current educational systems. In our view, the inclusion of future-oriented pedagogies in science education is a key step towards sustainability-competent citizenry.

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