frontiers | Frontiers in Education

TYPE Curriculum, Instruction, and Pedagogy
PUBLISHED 28 September 2023
DOI 10.3389/feduc.2023.1085526

OPEN ACCESS

EDITED BY
Carolin Enzingmüller,
University of Kiel, Germany

REVIEWED BY
José Cravino,
University of Trás-os-Montes and Alto Douro, Portugal
Emily Michailidi,
University of Crete, Greece

*CORRESPONDENCE
Francesco De Zuani Cassina
✉ francesco.dezuani2@unibo.it

RECEIVED 31 October 2022
ACCEPTED 04 September 2023
PUBLISHED 28 September 2023

CITATION
De Zuani Cassina F, D'Orto E, Tasquier G, Fantini P and Levrini O (2023) Enhancing relevance and authenticity in school science: design of two prototypical activities within the FEDORA project.
Front. Educ. 8:1085526.
doi: 10.3389/feduc.2023.1085526

Enhancing relevance and authenticity in school science: design of two prototypical activities within the FEDORA project

Francesco De Zuani Cassina*, Emma D'Orto, Giulia Tasquier, Paola Fantini and Olivia Levrini

Department of Physics and Astronomy "Augusto Righi", University of Bologna "Alma Mater Studiorum", Bologna, Italy

We live in a historical period that sociologists call the "society of acceleration", where changes, mainly triggered by science and technology, occur over increasingly shorter time intervals. International reports by the OECD, the European Commission, and UNESCO highlight a worrying detachment between scientific education at school and societal issues, in terms of topics and practices. To address this gap, the H2020 project FEDORA[1] designed and implemented several school activities centered around topics related to current challenges, aimed to increase students' feeling of relevance toward formal scientific education. These implementations are: (i) based on the three FEDORA framework's theoretical pillars: *interdisciplinarity, search for new languages, future-oriented education*; (ii) informed by some FEDORA's recommendations to curricula developers, then turned into operational design principles: *cross and integrate different disciplines, elicit epistemic emotions*, *embrace and embed complexity and uncertainty*, *dismantle dichotomous thinking and telling*, *exercise scenario building and thinking about the future in a pluralistic way*. After presenting the general framework and the recommendations, we will discuss the details of two activities ("Mocku for change," "Physics of clouds") which, respectively, exploit the use of creative writing and mockumentary as forms of new languages. They concern topics such as sustainability or complexity and are aimed to help students engage and make sense of contemporary challenges in a personal and emotional way. In the end, we will argue why we consider them to be examples of practical and (to some extent) reproducible activities in class, which could reduce the gap between science at school and science outside school; in this sense, we claim to shed light on possible ways by which formal educational systems can reposition themselves to deal with societal needs.

KEYWORDS

relevance, authenticity, scientific practices, STEM identity, mockumentary, creative writing

1 https://www.fedora-project.eu/

1. Introduction

We live in a historical period that the sociologist Hartmut Rosa named the "society of acceleration" (Rosa, 2009); the development of science and technology imposes such rapid changes that societal institutions are struggling to keep up with them. Artificial intelligence, quantum technologies (European Commission et al., 2021), cryptography, mobility, and many more, are examples of challenges that have been transforming very rapidly in the last few years and which also have a great impact on society. Moreover, climate change and socio-political crises are strongly and widely inducing a sense of urgency to address sustainability issues.

Policymakers and science education researchers are trying to push for schools to play an intermediary role between students and the most demanding present-day challenges, to promote an educational curriculum that could help to make sense of society and its development, as well as to develop a sense of agency. Signs of this intention can be found in many recent reports by research commissions: for instance, the European Commission in the "Council Recommendation on learning for environmental sustainability" highlights the "*role of education in empowering people for environmental sustainability […] Schools, universities and other education and training institutions will become places where sustainability is not only taught but also actively practiced*" (p. 8). Also, the 2021/C 66/01 Resolution of Council of the European Union (2021) shared some recommendations which aim to foster "*creative approaches in green education […] and promoting educational concepts, such as Education for Sustainable Development and Global Citizenship Education, in order to empower citizens to contribute to sustainable development*" (p. 21).

Along the same lines, many "competence frameworks," released in recent years, aim to map the skills needed to face such kinds of challenges. For instance, in 2022 the European Commission launched the GreenComp, the European sustainability competence framework, in order "*to improve and develop the knowledge, skills and attitudes to live, work and act in a sustainable manner*" (Bianchi et al., 2022). The European Commission also launched the Digital Competence Framework for Citizens–DigComp (Vuorikari et al., 2022), which fosters students' ability to solve problems by creatively using digital technologies, since "*in a growing technological world, these skills become part of their citizenship training to participate in the digital society where they will live*" (Pedrò et al., 2019). These competence frameworks point out a way to develop skills that will be soon required as citizens' skills, by reshaping the society that faces us.

Related to what has been said so far, to promote general awareness of the current challenges, further approaches have been outlined, which instead set out to use art as a means for science communication and public engagement. "STEAM (Science, Technology, Engineering, Arts, and Mathematics) education" is an approach advocating the need and relevance of including Art & Design in teaching/communicating STEM subjects. It has been adopted and developed, for example, by Science Gallery (SG), an international university network of galleries set up to "ignite creativity and discovery where science and art collide." SG locates creativity at the core of both scientific and artistic discovery, and its vision conceives "a world where creativity knows no boundary." From the SG perspective, some of those boundaries are represented by siloed disciplines and outdated curricula that lack a future-proofing approach. By fostering interdisciplinary collaborations among researchers, artists and[2] industries, Science Gallery produces expositions, workshops, events and learning programs. Hence, the Science Gallery Network and more generally the STEAM approach can be considered an example of how merging arts with STEM education can be fruitful in improving student engagement, creativity and problem-solving skills (Liao, 2016); in addition, such an approach can create a connection with social/political issues that can help STEM disciplines and STEM education leading the strong innovation this century requires (Maeda, 2013). STEAM research showed how that kind of approach could help to improve the learning satisfaction and motivation of students toward sustainability issues (Kim et al., 2017; Hsiao and Su, 2021) and more specifically Climate Change issues (Jacobson et al., 2016; Moser 2016).

In this view, exploring artistic languages finds a particular role in future-oriented science education: to create an interdisciplinary space to nurture young students' imagination and active hope toward sustainable STEM innovation.

1.1. Research context and goals of the study

Despite the urgency and importance of aligning school curricula with societal needs, formal educational systems are struggling to reposition themselves concerning current challenges and related policy recommendations. Indeed, so far, almost half of national curricula worldwide still do not refer explicitly to climate change issues (UNESCO, 2021). As the OECD also revealed, "*societal and environmental changes are happening rapidly, and technologies are developing at an unprecedented pace, but education systems are relatively slow to adapt*" (OECD, 2019). Among other issues, two gaps within formal science education are progressively emerging between what students experience at school and what they experience in everyday life outside school.

On the one hand, doing science at school is perceived as something strongly different from the common image of doing science within scientific communities; this distance is at the level of *practices*. Hence, the larger this gap is perceived to be by students, the more the *authenticity* (Kapon, 2016; Kapon et al., 2018) of school scientific practices is questioned. Specifically, we frame *authenticity* by borrowing from Kapon (2016): authenticity in the sense of letting learners explore scientific ideas and questions in a community-like class setting (Barton, 1998; Windschitl et al., 2012; Stroupe, 2014; Miller et al., 2018) or the authenticity of making students and teachers interact with science practices and activities (Wormstead et al., 2002; Houseal et al., 2014). On the other hand, as already said, topics related to challenges such as climate change and sustainability or artificial intelligence do not find space within every school's scientific curriculum, and this could increase the gap between school and society; here the gap is at the level of *topics*. Scientific themes tackled

2 Information about Science Gallery Network mission and values are declared in the section "What Science Gallery does" of their website (https://sciencegallery.org/what-sg-does) and in their internal (for network members only) toolkit (https://toolkit.sciencegallery.org/about-science-gallery/our-mission-values/).

in class sometimes appear disconnected and far removed from present-day challenges, and this establishes a mismatch between the *relevance* of science within and outside school. The mismatch inhibits learning that is personally meaningful and relevant for students (Kapon, 2016). We frame a "meaningful and relevant" learning, elaborating on the concept of *relevance* discussed by Stuckey et al. (2013): something is considered relevant when it contributes to the development of identity (personal relevance) and the competencies (societal relevance) needed to participate in societal sustainable growth. A lack of personal relevance (Levrini, 2015) for science education (in terms of practices and topics) instead, could imply obstacles to STEM identity development. Indeed, scientific disciplinary identity is fostered when the practices enacted by the individuals are recognized as relevant for the community of practice (Wenger, 1998); if the practices and topics that find space in class (the only ones enacted by students) are different from those which make sense in "real" scientific communities, students have little chance of feeling like participants in "science-construction" and thereby developing a scientific identity. Hence, engagement, interest and identification with STEM disciplines decrease (Hazari et al., 2010; Potvin and Hazari, 2014).

Considering the above, it seems fundamental to include schools in this debate; a re-configuration toward future-oriented curricula is advocated in terms of current challenging topics and related competencies (OECD, 2019; Pedrò et al., 2019). Additionally, we claim that there is a need for design principles which could map this debate to a more practical level, and lead to specific instructional activities and learning modules.

The objective of the present work is therefore to present the design of two prototypical activities carried out at school, in two different contexts, which question the image of science as non-relevant and set out to reduce the gaps between school science and real science, both in terms of topics and practices. The activities are inspired by the general approach of our research, with the ambition to allow students to experience the richness of science by "immersing them" in its epistemological and social features. We claim that this work represents an example of how it is possible to inform school science with the guidelines and reflections emerging from educational policy reports and science education research.

In the next section, we will first describe the FEDORA approach (our general research), and from this starting point we will articulate the rest of the paper by illustrating:

(1) the set of recommendations emerged from the theoretical frameworks elaborated within FEDORA and then turned into principles that oriented the design of FEDORA prototypical activities;
(2) the ways these principles have been operatively applied and enacted to design and implement two emblematic FEDORA prototypical activities.

2. FEDORA framework and background

The FEDORA project (see text footnote 1) started in 2020, as part of the Horizon 2020 program, and includes a network of experts at the nexus of science education, science communication and society. The project has the general aim of developing a future-oriented model for both formal and informal science education, which can equip youngsters with the thinking, foresight and action competencies needed to grapple with societal challenges. The intention is to foster a change in the view on schooling and the role of science education in addressing societal challenges and the science-society gap, as well as to support proactive and anticipatory policymaking on this issue.

To that end, FEDORA is working on three forms of misalignment identified between the educational system and society: (i) a clash between the hyper-specialized organization of teaching in disciplines and the inter-multi-transdisciplinary character of innovation; (ii) a mismatch between the formalized languages and the need for new languages to enhance the capacity to talk about contemporary challenges; (iii) the discrepancy between atemporal teaching approaches and the need to support students to construct visions of the future by empowering actions in the present.

The three mismatches have then been re-formulated into three *research pillars* addressed by the first three working packages (WPs) of the project: interdisciplinarity (WP1), search for new languages (WP2), and future-oriented education (WP3). As one of the final research findings of the project, these three main pillars resulted in three frameworks (FRs), respectively named:

FR1—Framework for aligning science teaching/learning in formal contexts with the modus operandi of R&I: new inter-multi-transdisciplinary forms of knowledge organization for co-teaching and open-schooling (Pucetaite and Rauleckas, 2023),

FR2—Framework for aligning science education with society: the search for new languages and narratives to enhance imagination and the capacity to talk about contemporary challenges (Troncoso et al., 2023).

FR3—Framework to Futurize Science Education (Rasa et al., 2023).

Based on the analysis of the misalignments, these three frameworks pointed out the main related issues and elaborated specific recommendations intended to address those issues.

Concretely, the recommendations resulting from the three research pillars were turned into design principles operatively enacted through the FEDORA implementations (Figure 1).

2.1. The three research pillars

The first pillar (*interdisciplinarity*) stands, among others, on two theoretical frameworks. The first is the "FRA[3] to NOS Reconceptualization" framework (Erduran and Dagher, 2014), which unpacks scientific disciplines into different components belonging to the cognitive-epistemic or the social-institutional dimensions and provides a more holistic picture of the nature of science. The "FRA to NOS" framework has been used to reflect on the epistemic core of a discipline; in class, it is recommended for designing activities aimed at providing students with a foothold vocabulary to articulate a comparison of the epistemic cores of disciplines (Satanassi et al., 2023). The educational potential of epistemic cores is that they provide

3 Family Resemblance Approach.

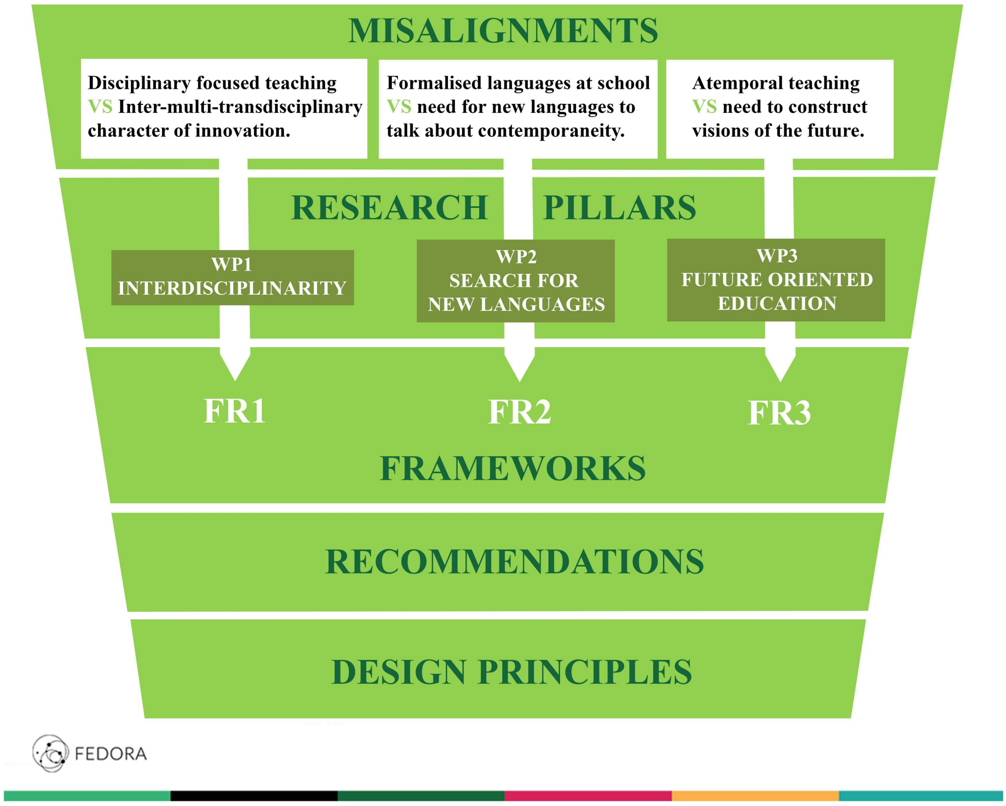

FIGURE 1
Design-process diagram. From top to bottom: three misalignments between education environments and society's labor market and R&I were identified; FEDORA's three research pillars were established, and three research frameworks were crafted; research shade light upon some crucial issues and some recommendations were designed to address them; finally a selection of relevant recommendations was made which brought to the creation of design principles for the development of educational activities.

examples of reasoning's structures, rigor's criteria, explication of principles, and dealing with these features train students' "sense-making" skills (Tasquier et al., 2022b). The second framework we rely on is the meta-theory of boundary objects and mechanisms elaborated by Akkerman and Bakker (2011). In their work, the authors discuss the different figures that populate boundaries (boundary people, boundary objects) and the diverse boundary-crossing mechanisms (identification, reflection, coordination, transformation). In FEDORA, the conceptual richness of this "boundary metaphor" has been used to model interdisciplinarity and its "paradoxical" nature: boundary both separates and connects. Interdisciplinarity blurs and redefines disciplinary identities and requires managing the equilibrium between "sense-making skills" (Kapon, 2017)—systems, critical and analytical thinking—and "strange-making skills" (Bol and de Wolf, 2023)—creative, imaginative and anticipatory thinking (Levrini et al., 2023; Pucetaite and Rauleckas, 2023). The FEDORA elaboration on these two frameworks resulted in FR1's recommendations which argued that interdisciplinary teaching opens rooms for creating value at different scholastic levels (from primary school to university contexts) and that managing interdisciplinarity requires reworking the concepts and methods that characterize the identities of different disciplines in a way that creates *boundary zones,* where to exchange, compare and integrate different disciplinary concepts and methods.

The second pillar (*search for new languages*) elaborates on the concepts of *engagement* and *innovation* (Troncoso et al., 2023) to explore possible ways for regenerating languages in science education. Engagement, in science education, is considered as a cognitive and emotional experience that results in a change of attitude. On the other hand, a language is considered innovative if it presents connections between science and other domains of knowledge, "*which can inspire a cognitive journey toward something not obvious at first but that becomes essential and personally relevant once touched upon*" (Tasquier et al., 2022b). In this sense, the STEAM approach is an example of how those non-obvious cognitive links between different domains of knowledge (scientific and artistic ways of making sense of the world) can be explored and fostered.

Hence, the FEDORA elaboration on *engagement* and *innovation* resulted in FR2's recommendations to orient the search for formats and languages able to foster a "value-laden *engagement* and an active role" of the students (Tasquier et al., 2022b). Furthermore, such formats and languages can be used to create a boundary zone where openness, contamination and co-designing are explored to "take down the walls," cross disciplinary boundaries, inhabit these new frontier zones and foster imagination toward future scenarios.

The third pillar (*future-oriented education*) reflects the ambition to adapt "future thinking" to science education (Carter and Smith, 2003; Jones et al., 2012; Paige and Lloyd, 2016; Branchetti et al., 2018; Levrini et al., 2021a,b). In this case, the pillar builds upon four main ideas resulting from an interaction between the analysis of the research literature and the empirical exploration of some case studies related to the issue of futurizing science education. Particularly, the FEDORA approach interconnects research in a variety of domains: future studies, youth studies, science and technology studies, and educational studies on agency, as well as societally oriented approaches to science education, such as the SSI (socioscientific issues) and STSE (science, technology, society, environment) movements. The FEDORA analytical framework draws from the extant research on four main ideas:

- *two-track thinking*: personal futures are often perceived by students as positive and in one's own hands, on the other side global futures are perceived as gloomy and beyond their control (Rubin, 2013; Cook, 2016). This leads to a polarization between individual and collective, and the creation of "safe bubbles" (Levrini et al., 2021a,b);
- the five dimensions of the Future Consciousness framework (Ahvenharju et al., 2018): these can be thought of as scaffolding principles for future thinking processes. Such dimensions (*time perspective*, *agency beliefs*, *openness to alternatives*, *systems perception*, *concern for others*) represent the prior conditions that allow future-oriented thinking and behavior to take place;
- a temporal perspective to frame the concept of *agency*, following the work of Emirbayer and Mische (1998); in this case, the "chordal triad of agency" will be used to foster students in the creation of future scenarios (*possible future, probable future, preferable future*);
- the central role of technology and its nuanced and complex role in future thinking, since technology has been shown as one of the main sources of transformation of the present into the future (Bishop et al., 2007).

The FEDORA elaboration on these four ideas, converged into FR3's recommendations, arguing that including in teaching future scenarios and how they could be related to technology development, can provide students with tools for connecting with and finding agency within their personal and global futures; as a consequence, it could provide a broad and deep perspective about how to overcome the idea of one future as prescriptive, unidirectional and imposed from above (Levrini et al., 2023; Rasa et al., 2023).

To wrap up, the recommendations that emerged by FR1-2-3 represented the synthesis of FEDORA project's findings and insights, targeted to policymakers, researchers in science education, and curricula developers and have been conceived as conceptual tools to imagine and design interdisciplinary, future-oriented, engaging, relevant, and meaningful science learning experiences for learners of different ages and backgrounds (Tasquier et al., 2022b; Pucetaite and Rauleckas, 2023; Rasa et al., 2023; Troncoso et al., 2023).

2.2. Toward the formulation of design principles: recommendations from FEDORA frameworks

In this section, we present a selection of the FEDORA recommendations that we have, then, turned into principles guiding the design of the two prototypical activities presented in the next section.

In describing the recommendations, we refer to the main research results that have been obtained in the part studies of FEDORA.

- *Cross and integrate different disciplines*: FEDORA, on the wake of another project (IDENTITIES),[4] indicates that interdisciplinary teaching creates value also for the disciplines and their teaching at different scholastic levels (from primary school to university contexts); indeed, valuing interdisciplinarity means reworking the concepts, aims, values and methods which define disciplinary identities. Disciplines and their epistemic cores are still considered crucial for guiding students to make and consolidate "structured" educational experiences. Such experiences represent a solid ground that is needed to develop a sense of epistemic identity, and from which a student can take up the process of crossing boundaries and developing interdisciplinary skills. In FEDORA the recommendation is to create a "third space" where disciplines can be compared, integrated and analyzed from different perspectives. Interdisciplinarity implies, at the personal level, changing the attitude and becoming a "disciplinary nomad," that is accepting the intellectual risk of going out of one's own comfort zone, to embrace the ambiguity (Levrini et al., 2023). At the same time, it implies balancing the development of *sense-making skills* (i.e., systems, critical, analytical thinking) and *strange-making skills* (i.e., creative, imaginative, anticipatory thinking) (Bol and de Wolf, 2023), about the tension between making disciplinary boundaries and crossing them.
- *Elicit epistemic emotions*: FEDORA research indicates that learning and thinking are entrenched with emotions, and the emotions felt in the learning process are named *epistemic emotions*. As Davidson argues, these emotions "*are experienced in the epistemic work of constructing and critiquing knowledge*" (Davidson et al., 2020). These are emotions concerning the subject's own mental capacities and mental processes (Arango-Muñoz and Michaelian, 2014) and are entangled with the conceptual and epistemological substance of the content (Jaber and Hammer, 2016). The objective is to leave room for the affect to become a tool, promoting a shift from emotive polarization (Levrini et al., 2021a,b) toward emotions coming from a critical approach to the discipline, emotions to support pro-action in imagining and pursuing the personal future. Hence, FEDORA recommends exploiting alternative forms of expression (e.g., artistic forms), in teaching and practicing a discipline, which could foster students to express and question their epistemic emotions.
- *Exercise scenario building and thinking about the future in pluralistic ways:* youngsters often have the idea of the future as prescriptive, unidirectional, imposed from above, and beyond their control (Cook, 2016). Thus, to enlarge the vision of the future means cultivating an ability to think in terms of multiple and possible scenarios; at the same time fostering a sense of agency in the future (Emirbayer and Mische, 1998) means taking into account values, dreams and choices to construct *plausible, possible and preferable scenarios*." Hence, FEDORA recommends developing activities where the future is represented as something still not defined, as a cone made of multiple possible scenarios (Voros, 2003), and engaging students in *scenario-building* workshops.

4 https://identitiesproject.eu/it/

- *Dismantle dichotomous thinking and telling:* youngsters have a dichotomous image of the future, as emerged within FEDORA WP3; particularly, a tension is noted between the collective one (beyond the control and detached from the individuals) and the individual one, manageable. This dichotomy leads to a polarization of thinking. Indeed, the individual future is (intellectually) approached with hope and positivity, given the sense of agency in it, whereas the collective one is populated with negative thoughts (Cook, 2016). Another strong dichotomy investigated within FEDORA is related to climate change and is the tendency to address future scenarios by studying raw projections of scientific data (non-fiction/reality) or, on the contrary, by picturing narrative but totally imaginative future scenarios (fiction/imagination) that are not based, or more generally do not consider scientific knowledge that comes from climate models. Hence, trying to overcome dichotomous thinking and telling means sharing a kind of knowledge that can go beyond the polarizations and overcome a binary vision of the world; it also means embedding in the language the intrinsic richness of shades world. Regarding this, FEDORA recommends designing activities aimed at sustaining strange-making skills (Bol and de Wolf, 2023), addressing scientific concepts by making use of artistic/creative format and languages, to create contexts of dialogue where the scientific discourse is created by leveraging on students' input and creativity and imagination are fostered.
- *Embrace and embed complexity and uncertainty*: physics epistemology has a high degree of complexity that can be exploited as a tool (Duit et al., 2012). The knowledge, practices, aims and values (Erduran and Dagher, 2014) which define the epistemic core of physics, should be highlighted in their conceptual depth rather than being simplified and trivialized in their meaning. An example is the educational potential of the concept of *uncertainty,* which is a crucial epistemological pillar of physics (Rosenberg et al., 2022). This epistemic richness (in terms of reasoning structures, rigor's criteria, explication of principles…) can be used as an instrument to train students' "sense-making" skills. Hence, FEDORA incorporated the recommendation to choose topics, models and concepts which are intrinsically complex and have uncertainty as a characteristic feature, and put them under debate so that they can trigger epistemic emotions related to complexity (Levrini et al., 2019a).

3. Design and implementation of activities

As mentioned previously, this paper is focused on two activities among those carried out by the Bologna Open Schooling Network—BOSN[5] implementations (Tasquier et al., 2022a; Tasquier and Barelli, 2023). In this round, three pilot experiences have been implemented, in parallel with the research work we were carrying out within WP1-2-3 of the FEDORA project. For the BOSN, the theme of the new languages was the main novelty as well as that which required a more creative effort in the design. Hence, as an example of how the issues of new languages were addressed through the design principles, in the next paragraphs we will present two of the three pilot activities. Namely, they are:

- an activity exploiting the *mockumentary* format to imagine realistic future scenarios induced by climate change ("Mocku for change");
- an activity on *creative writing* carried out to exploit the basic concepts of the science of complex systems as a metaphor to structure a story ("Physics of clouds").

3.1. Mocku for change

In his book *The Great Derangement* (Ghosh, 2017), Amitav Ghosh argues that contemporary literature is struggling to picture climate change because its most important genre, the modern novel, has features that are not suited to telling stories about the climate crisis. It is indeed true that, in highly regarded literary journals, the subject of Climate Change occurs almost always concerning essays or non-fiction and very rarely among novels or short stories (Ghosh, 2017); the same holds within the film industry. Therefore, in today's narratives, a strong dichotomy exists between fictional and non-fictional products, with Climate Change contributions linked mostly to the second group, except for an emergent fiction genre named Cli-Fi. Furthermore, Sci-fi and Cli-Fi are genres that have the merit, due to their features, of addressing the topic of the Future, and can be then incorporated within the framework of Future Studies.

Hence, by developing activities that make use of Cli-Fi genres, and so informed by the Future Studies approach, students are encouraged to develop skills to imagine possible and desirable futures. This can be conceived as a "scenario building" process, which has important educational consequences: by creating fiction of the future together, students begin to experience how much power they have in telling their own story—and thus to create their own future—without unthinkingly accepting the stories that are imposed on them by their culture (Burchsted and Byrne, 2001).

"Mocku for change" is a prototype activity that has been developed to explore the use of the film-making genre known as "mockumentary," addressing the topic of Climate Change; so, it can be considered as a Cli-Fi genre. Mockumentaries are fictional stories that appropriate the aesthetics of the documentary genre, using their same codes and conventions. At first, they might appear to be actual documentaries, which may lead to initial confusion or "ambiguity," then resolved with a "fictional flag."

5 This network has been established in collaboration with a wide variety of Italian secondary schools in terms of geographical distribution, relationship with the social community of the region, political role and relationship with policy-making structures, cultural background and tradition, internal organization, curricula, typologies of teachers, disciplines involved and internal expertise. Furthermore, the network involved other stakeholders including researchers in science education, scientists, artists, science communicators and language experts (video-makers, bloggers, writers and data story-tellers). The establishment of the network is part of the SEAS Project (https://www.seas.uio.no/).

In our activity, mockumentaries were used to help students build "fictional yet realistic" Climate Change scenarios by reflecting upon the differences between:

- *scenario* as a projection of today's scientific knowledge on Climate Change based on Climate models (reality/non-fiction),
- *scenario* as a projection into the future of our dreams, desires and epistemic emotions (imagination/fiction).

We claim that the power of the mockumentary genre in the pursuit of Climate Change scenario-building relies on its intrinsic property to overcome the dichotomy between fiction and non-fiction genres (D'Orto, 2022). It does so on the acknowledgement that, in the audio-visual field, reality is profoundly linked to our representations of it, meaning that there are some conventions that we as viewers associate with the perception of "real stories." Guiding students in the creation of a mockumentary about Climate Change, while reflecting upon the differences between the two kinds of scenarios mentioned above, means leading them toward a scenario-building process that finds a new balance between "*fiction*" and "*non-fiction*" on both stylistic and narrative levels.

In light of the above, we present how previous recommendations were "projected" becoming principles for the activity design:

- *Cross and integrate different disciplines*: Learn concepts and linguistic tools from three very different disciplinary scopes (physics, future studies and mockumentary art) and use them to address the same topic (climate change). The process of creating an artifact at the boundary of different disciplines and their linguistic constraints offers the opportunity to reflect on knowledge organization and communication. In particular, the artistic language allows students to attach thoughts and feelings to scientific content and create artifacts that are "embodied meanings" (Catania, 2023).
- *Elicit epistemic emotions*: allow young people to unload the psychological burden of the climate crisis by picturing desirable or undesirable futures in the form of imaginative yet realistic scenarios, to connect instinctive feelings to epistemic emotions (Jaber and Hammer, 2016) and move from spontaneous fear to active hope.
- *Dismantle dichotomous thinking and telling*: support students in addressing what Ghosh (Ghosh, 2017) called the "imaginative and cultural failure that lies at the heart of the climate crisis," by trying to overcome the main dichotomy (fiction/non-fiction) and other typical dichotomies related to Climate Change (e.g., individual/collective, reflection/action, simple/complex), that might block or impair the imagination of the future.
- *Embrace and embed complexity and uncertainty*: help students to deal with uncertainty by investigating "probabilities" and "possibilities." By creating fictions of the future together, students begin to experience how much power they have to tell their own stories. Educating the imagination by helping it to be flexibly oriented toward the future means that we approach the future not with a belief about what it will be, but instead with a set of possibilities.
- *Exercise scenario building and thinking about the future in pluralistic ways*: use scenario building to help students deal with a theme that involves not only a scientific dimension but also geopolitical aspects like governance, economics, and conflicts, or socio-cultural issues like human rights and education. Scenarios are stories designed to help break the habit of assuming that the future will look much like the present, creating a safe space for dialogue and uncertainty, by realizing that human-made climate change is driven by a myriad of societal factors over decades and centuries to come.

3.1.1. Context and structure of the activity

"Mocku for change" was conducted within a Laboratory of Climate Change carried out in 2021, within the context of "Piano Nazionale Lauree Scientifiche" (PLS) at the Department of Physics and Astronomy of the University of Bologna. The PLS laboratories aim to offer students the opportunity to approach advanced research topics and get to know what the "profession of the physicist" looks like. These laboratories stress the intertwining of physics with other disciplines and its implications on a social level, and they also foster students to develop the soft skills (creativity, planning, communication skills, teamwork) required by the world of labor.

The total duration of the prototype activity was 13 h: 4 h of frontal yet interactive lectures about the science of climate change and 9 h of laboratory sessions. The participants were 45 students between 17 and 19 years old (grades 12–13).

The prototype implementation was structured in 3 phases. Firstly, all groups attended an introductory lecture of 2 h about the mockumentary genre. This session was designed to introduce the main topics, collect data on students' previous knowledge of those topics, and let them gather ideas for the next phase. Phase two was the operative stage, consisting of three laboratory sessions of 3 h each, aimed at supporting each group on technical aspects of the mockumentary-making process. Finally, the last phase was a two-hour lecture structured in the form of an Interactive Film Festival, meaning that it involved screenings of the produced mockumentaries, voting and awards. It was aimed at collecting data on the impact that mockumentaries have on the audience and discussing the process of making the mockumentary.

The activity was a prototype and exploratory. This means that the methods of data collection and data analysis chosen were mainly aimed at "capturing a signal" that could reveal something about the potential of this new form of language. Data collection included questionnaire answers and student artifacts. A thematic analysis was conducted. Mixed methods of data analysis were used, both quantitative and qualitative, according to the typologies of data collected and the scopes of each analysis.

3.2. Physics of clouds (*Fisica delle nuvole*)

The "Physics of Clouds" activity emerged to test the belief that it is possible to exploit the educational potential of the science of complex systems to equip young students with conceptual, emotional, and epistemological tools needed to navigate our fast-changing society. Indeed, we claim with Jacobson and colleagues that *"the conceptual basis of complex systems ideas reflects a dramatic change in perspective that is increasingly important for students to develop as it opens up new intellectual horizons, new explanatory frameworks, and new methodologies that are becoming of central importance in scientific and professional environments"* (Jacobson and Wilensky, 2006, p. 12).

In the activity, core features of complex systems such as multiplicity, irreducibility, circular causality, unpredictability and self-organization, were selected as scientific contents; hence the presentation of the contents has been done by referring to complex systems encountered in everyday life, like flocks of birds, anthills, clouds.

The objective of the activity was to allow students to increase epistemic skills such as *aggregate* and *agent-based* perspectives (systemic view on the system), and *bottom-up* or *top-down* perspectives (attention to the causal processes) (Jacobson and Wilensky, 2006): in general, the ability to have a systemic view. With this aim, the epistemological structure of the science of complex systems is explicitly unveiled to guide the students to: (a) recognize emergent properties in dynamical systems, (b) get to know the different levels of description (the "micro" level of the agent, the macro-level of the whole system and the mid-level needed to explain the emergent properties) (Barth-Cohen, 2018) and the mechanisms of interaction among the levels; (c) reflect on the impact of individual actions on the systems and *vice-versa*; (d) recognize the new kind of causality introduced, with respect to the one of classical mechanics (circular causality vs. linear causality); (e) observe the contraposition between a deterministic system (classical) and chaotically deterministic (so unpredictable) system (complex).

It is also noteworthy that "Physics of Clouds" leverages the potential of interdisciplinarity to make the concepts and the physics epistemic structure more and more transparent. Consistently, the activity foresees a "process of translating" the scientific contents into a story, built according to the constraints of "creative writing." This process of translation was guided as a process of re-conceptualization aimed to both clarify and enrich concepts' meaning. The activity was also expected to encourage students to search for a personal approach to populate the concepts with their tastes, needs and meaning.

In light of the above, we present how previous FEDORA recommendations were "projected" into this second activity[6] oriented its design:

- *Cross and integrate different disciplines:* design and activate a process of translation from one disciplinary language (physics) to another (creative writing). In the translation, make the disciplinary and narratological constraints visible to foster the conceptualization in one domain (scientific) and the re-conceptualization in another domain (narrative). Creative writing allows to conceptualize again the physics content, since writing has an intrinsic *space of freedom*, beyond the narratological constraints; this space can be populated by students' thoughts about the contents (complex systems) and can enrich the meaning attached to the content itself.
- *Elicit epistemic emotions*: create a shared space in which students can experience and work on epistemic emotions. Indeed, complex systems are epistemologically revolutionary, since the very basic foundations of classical physics are questioned; the complex system heuristics then implies a cognitive (Abrahamson and Wilensky, 2005) but also emotional challenge to deal with. Hence, take care of guiding the emotions of discomfort, and problematize any polarization attitude to label such epistemic emotions into only positive and negative ones. Instead, take care of fostering any attempt to feel, recognize and name emotional nuances in dealing with the challenge of the activity.
- *Dismantle dichotomous thinking and telling:* exploit the concepts of complexity which can help to promote the ability to overcome the dichotomy between the individual and the collective dimensions. More specifically, use the science of complex systems to activate a reflection on the relationship between emerging collective structures and individual agency, highlighting *aggregate* and *agent-based* perspectives. This implies emphasizing concepts such as the circular relationship between the whole and the parts; the rules which individuals (agents) obey in modeling a complex system, and the emergent properties of the system.
- *Exercise scenario building and thinking about the future in pluralistic ways*: exploit the science of complexity as a source for developing future-scaffolding skills (Levrini et al., 2019a); this implies stress the importance of events, chance, probabilistic nature of the emergence of new organized structures. It also implies educating on the concept of scenarios and being ready for the possibility that many different scenarios may open up.

3.2.1. Context and structure of the activity

The activity took place at Liceo A. Einstein in Rimini (scientific secondary school). It was implemented as a curricular course over 3 months (March–May 2021) for about 50 h. It involved a class of 24 students in the first year of high school (9th grade) and three teachers, one of physics,[7] one of literature and one of history. The lessons were taught by the physics and literature teachers, while the writing workshop was managed by the literature teacher with the help of the history teacher. The activity was structured by intertwining interactive lessons and workshops.

The scientific concepts were introduced by the physics teacher (with the presence of the other two teachers) in four lessons (1 h each). Using examples from everyday life, the central concepts of complexity were investigated by identifying what were termed "the words of complexity" (multiplicity, irreducibility, circular causality, unpredictability, self-organization). The lessons were followed by working group sessions designed to consolidate the concepts learned.

At the same time, during curricular hours, the literature teacher presented the writing and narratological techniques through the reading, analysis and commentary of short stories. An analytical reading was made of Italo Calvino's short story collection "Palomar," to show a particular narrative structure in which elements of complexity can be traced.

Finally, in a one-hour lesson where all three teachers were present, a critical reading of the Palomar tale "Reading a wave" was made, from the perspective of complex systems. The aim was to make explicit how

6 Adherence to the design principle "*Embrace and embed complexity and uncertainty*" is in the choice of the content itself. The theme of the activity (complexity and complex systems), developed in both literary and scientific languages, requires systemic and (at the same time) imaginative thinking capable of handling uncertainty and unpredictability. For this reason, we consider this principle as "structural" in the activity.

7 The physics teacher is a retired physics teacher, who used to work for many years in that school; she was not the in-service physics teacher of that class.

Calvino manages the intertwining of the two fields, scientific and literary, and how the narrative structure can be interpreted in terms of complexity.

In the last part, students attended the writing workshop (led by the literature and history teachers): divided into six groups of four students each, they wrote the stories as a joint effort, documenting the work with a logbook. The teachers assigned each group a specific context in which to set the story; this context was represented by a complex system (anthill, cloud, flock of birds, fluid, nest). During the writing workshop, the teachers held an ongoing discussion with each group about how the narrative should address the concepts of complexity while respecting the narratological constraints. By "narratological constraints" we mean that students were asked to use different kinds of narrative sequences (reflexive, dialogues, descriptive); they were also required to make use of a "beginning sequence," as well as to elaborate on the duality between two main characters, where "the other" is used to question the balance of protagonist status, through his/her words.

The stories were collected at the end of the activity, and then the first, third and fifth authors passed through several reading iterations. In addition, a thematic analysis has been done, with many steps of category-refinement and triangulation, by the first and the fifth author, to see what themes were emerging from the data.

4. Discussion

The two prototype activities that we described in the paper were constructed on very similar, if not the same, design principles and, as we will document in other papers (De Zuani and Levrini, 2022), both activities were very well-received by the students. In particular, they were both designed to "*Cross and integrate different disciplines*." The intrinsic features of the disciplines involved (physics, creative writing and mockumentary), in terms of their languages, concepts and epistemological structure, were valued and combined in such a way that the features of one discipline could act as the scaffolding for the other. In other words, they were both designed as examples of interdisciplinary activities where the disciplinary constraints of one discipline opened up new opportunities to unveil knowledge embedded in the other discipline.

However, the two activities implemented the principle in a very different way. In "Physics of clouds," the two systems of constraints were very tight, and the strong narrative constraints required by the creative-writing domain were explicitly used by the teachers to unpack the content of the science of complexity. On the other hand, the "Mocku for change" left much more freedom to students, since the disciplinary constraints were less evident in that case. The mockumentary's multiplicity of narrative tools was thought to inspire students to address in many ways the relationship between knowledge and imagination, pairing this richness with a total freedom of choice of the climate change issue to focus on. The comparison of the two activities showed that the students of the second activity perceived the prompt for the project as too vague and a group overwhelmed by the big array of new and unexplored opportunities for expression, struggled to find a good idea to work on and risked not completing the video. Concerning this, the activity is now under revision to improve the balance between "freedom" and "guidance." The way that the designer (ED) is exploring is to show fewer mockumentary techniques or to let students focus their attention and imagination just upon some selected climate change issues, by asking, for example, to craft a story that tells about a solution to a specific challenge that climate change poses to our society.

The comparison of the modules leads to recognize that a critical issue regards the equilibrium between the amount of support and the space left for students' exploration of the new languages as well as their contribution to the artifacts; a process that is well depicted by the metaphor "pulling the rope and letting it go," used by the third author in another work (Fantini et al., 2014; Levrini et al., 2019b). Despite those difficulties and thanks to teachers' strong commitment, students in the end started to see the general ambition of the activities, learning that approaching science phenomena with societal implications (e.g., climate change) implies both a change in the epistemological way of looking at the phenomena themselves and a change in how knowledge influences decisions. Students recognized and appreciated the ideas behind the projects, and their connection with real-life topics, and were satisfied that finally something at school was being done "*for them*," in ways "*close to them*."

They expressed these thoughts with the teachers, with the first author of this paper, and even the families shared their positive impressions. One interesting comment comes from one of the logbooks of the groups of "Physics of clouds": "*One thing I have noticed through this work is that when I am walking or riding in a car/bus I observe my surroundings and try to understand more about that place/object/man even if I only see it for a second. Complexity does not exist only when you realize it, when you really find out what it means. Complexity is everydayness and it just exists*."

As regards the challenges, another one was faced within "Physics of clouds," because of the many hours spent on a project that was not structural within the curriculum. The teachers deliberately chose to implement the project within the curricular schedule, since they wanted to trigger educational and emotional dynamics involving the whole class. This choice had two main consequences:

- the constant search for a balance between staying *somehow* connected with the ordinary Italian literature curriculum of grade 9 (for example by inserting literature contents, key readings, etc., within the project) and not lag behind other classes, and on the other hand to carefully cultivate the novelty of the creative writing process. So, the teacher had to redefine the curriculum according to the innovative activity but respecting the institutional curricular constraints. Furthermore, it is worth reminding that this new equilibrium had to be shared and accepted by the whole class council;
- the problem of assessment, since it was a curricular activity. In this case, the teacher was forced to give students marks at the end of the 2 months, evaluating the process of writing and the essays made (and it was not easy since they were divided into groups), but also assessing the level of participation. The essays passed through multiple editing steps, and at each step partial evaluation had to be made and considered in the final assessment. In spite of the non-standard evaluation procedure, the school and the families were very supportive, also because of the contextualization of the activity within an European project, the acknowledged quality of the work and the strong engagement of the students. However, this aspect can be an issue for the reproducibility of the activity in other contexts.

5. Conclusion

In this paper we started by naming some problematic issues that challenge science education and science communication in the society of acceleration (Rosa, 2009); then we presented the FEDORA project, which informed the design and implementation of the activities shown. We discussed in detail the theoretical pillars of the project, and how these lead to the formulation of issues and related recommendations for policymakers, researchers in science education, and curricula developers, as well as teachers, to imagine interdisciplinary, future-oriented and engaging learning experiences. We later explained how the general recommendations were considered to construct design principles for the two specific activities. Those activities are shown in detail in section 3 as examples of modules that can be used to explore practical solutions for bringing challenging topics to school. At the same time, the activities show possible interdisciplinary approaches exploiting languages coming from different fields (intertwining physics and creative writing, physics and mockumentary). Furthermore, we argue that by illustrating how the research in science education informed the design of interdisciplinary modules, we are answering what the European Commission is requesting. Indeed, "*many educators say they lack training and support in sustainability education and training, in particular, regarding interdisciplinary approaches*" (European Commission, 2022, p. 8); we claim that getting to know about the design process of strongly interdisciplinary activities, grounded on sustainability and societal related contents, can be a resource for educators' training.

We also believe that the two activities could be reproducible examples of how schools can play a fundamental role in the debate occurring among policymakers, science communicators and science education researchers, regarding the gaps between school science and real science. Indeed, considering for example "Mocku for change," it is easily reproducible in terms of costs, because videos can be shot on mobile phones and easily edited on mobile or PC using open-source editor applications/software: this aspect was reported as not obvious by both some teachers and some students involved and the discovery of this easiness in acquiring tools and learning how to use them to make an "edited" video was very appreciated. However, even if the practical skills needed for an activity of this kind are easy to acquire, the same cannot be said about learning the cinematic language and exploiting all its potential; this is why, to support and guide students throughout the activity, the teacher/implementer need to have or acquire not just video-making skills but also some good knowledge of the mockumentary genre. Moreover, although the activity was originally designed to tackle climate change issues, we think that *mockumentary* could be usefully explored to address other relevant scientific issues.

Concerning "Physics of clouds," it is our opinion that it can be also reproduced in other contexts, both curricular and non-curricular. In our case, the teachers wanted to include the workshop in the curricular hours to make it structural and emphasize its cultural value. Italian school syllabus is not particularly rigid, but there are shared timetables and programs; to include such a consistent project in the curricular program required a special conviction of the teachers on the strong educational value of the activity. However, the outcomes of the implementation of the "Physics of Clouds" are supporting teachers' conviction. In fact, from a preliminary analysis of data collected during the implementation, a special form of students' engagement with science topics and practices is emerging: students used science epistemology as a "space" where to represent, re-conceptualize, re-address issues related to their *core identity* (Gee, 2000). In particular, the dualism between "agents" and the "system" in complex systems behavior, was used as a *scaffolding* for the expression of the tension between the "individuals" and the "group," which is projected in the essays into the family, the peers (flock), the society. This tension expresses the delicate balance between a sense of comfort in staying with the group, and the need for independence and self-affirmation, a very common and distinctive phenomenon for teenagers (De Zuani and Levrini, 2022). For this reason, the teachers and the researchers decided to repeat the activities, to involve more and more teachers of different disciplines, and to push the class councils and the schools until they become structural activities, embedded in the disciplinary curricula. For example, we are implementing at the moment a follow-up activity of "Physics of clouds," which is named "Kairos,"[8] with a grade-10 class in the same school. This time we were able to involve (besides the retired physics teacher and Italian literature teacher) the in-service physics teacher, the in-service chemistry teacher and two laboratory technicians.

In conclusion, the plan for the future is to analyze the implementation of this new module, analyze the artifacts made, and extend the discussion around such activities to more and more teachers within Liceo Einstein and the larger frame of Bologna Open Schooling Network.

Data availability statement

The original contributions presented in the study are included in the article. Further inquiries can be directed to the corresponding author.

Author contributions

FDZ took responsibility for guiding the writing of the whole paper and coordinated the revision of the manuscript. FDZ, GT, and ED wrote the main parts. ED and GT designed and personally led the implementation of "Mocku for change" and wrote the related sub-section. PF designed and personally led the implementation of "Physics of clouds" and wrote the related sub-section. OL coordinated the whole group and the process of progressively revising the manuscript. All authors contributed to the article and approved the submitted version.

Funding

This research was conducted within the Horizon 2020 project FEDORA (Future-oriented science education to enhance

8 Kairos is one of the four names that ancient Greeks used when talking about "time." The other three are: aiòn, chrònos and eniautòs. Each of these terms highlights a different nuance of time (circular, absolute or relative).

responsibility and engagement in the society of acceleration and uncertainty), which has received funding from the European Union's Horizon 2020 Research and Innovation Program (grant agreement no. 872841).

Acknowledgments

Special thanks to Sara Moresco, the literature teacher who co-designed and led the creative-writing activity. Furthermore, we would like to thank all the partners involved in WP1-WP2-WP3 of the FEDORA project, for their contribution in inspiring the design principles.

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.

References

Abrahamson, D., and Wilensky, U. (2005). Collaboration and equity in classroom activities using statistics as multi-participant learning-environment resource (S.A.M.P.L.E.R.). Paper Presented at the Annual Meeting of the American Educational Research Association, Montreal.

Ahvenharju, S., Minkkinen, M., and Lalot, F. (2018). The five dimensions of futures consciousness. *Futures* 104:1016. doi: 10.1016/j.futures.2018.06.010

Akkerman, S. F., and Bakker, A. (2011). Boundary crossing and boundary objects. *Rev. Educ. Res.* 81, 132–169. doi: 10.3102/0034654311404435

Arango-Muñoz, S., and Michaelian, K. (2014). Epistemic feelings and epistemic emotions (focus section). *Philos. Inqu.* 2. doi: 10.4454/philinq.v2i1.79

Barth-Cohen, L. (2018). Threads of local continuity between centralized and decentralized causality: transitional explanations for the behavior of a complex system. *Instr. Sci.* 46, 681–705. doi: 10.1007/s11251-018-9454-4

Barton, A. C. (1998). Teaching science with homeless children: pedagogy, representation, and identity. *J. Res. Sci. Teach.* 35, 379–394. doi: 10.1002/(SICI)1098-2736(199804)35:4<379::AID-TEA8>3.0.CO;2-N

Bianchi, G., Pisiotis, U., and Cabrera Giraldez, M. (2022). *GreenComp the European sustainability competence framework*. eds. Y. Punie and M. Bacigalupo (Luxembourg: EUR 30955 EN, Publications Office of the European Union).

Bishop, P., Hines, A., and Collins, T. (2007). The current state of scenario development: an overview of techniques. *Foresight* 9, 5–25. doi: 10.1108/14636680710727516

Bol, E., and de Wolf, M. (2023). Developing futures literacy in the classroom. *Futures* 146:103082. doi: 10.1016/j.futures.2022.103082

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. Sustain.* 9, 10–26. doi: 10.13135/2384-8677/2770

Burchsted, S., and Byrne, J. M. (2001). *Shaping our future: facilitator's guidebook*. Shelburne, VT: Foundation for Our Future.

Carter, L., and Smith, C. (2003). Revisioning science education from a science studies and futures perspective. *J. Future Stud.* 7, 45–54. doi: 10.1080/03057260408560205

Catania, A. (2023). *An interdisciplinary course based on Tomás Saraceno's aerosolar sculptures searching for new languages in physics education*. (unpublished master thesis), University of Bologna, Text available under request.

Cook, J. (2016). Young adults' hopes for the long-term future: from re-enchantment with technology to faith in humanity. *J. Youth Stud.* 19, 517–532. doi: 10.1080/13676261.2015.1083959

Council of the European Union (2021). *Council resolution on a strategic framework for European cooperation in education and training towards the European education area and beyond (2021-2030) 2021/C 66/01*. Official Journal of the European Union.

D'Orto, E. (2022). *Mocku for change: An explorative study on the use of "mockumentary" as a new language for climate change education (unpublished master thesis)*. University of Bologna, Bologna.

Davidson, S. G., Jaber, L. Z., and Southerland, S. A. (2020). (2020) emotions in the doing of science: exploring epistemic affect in elementary teachers' science research experiences. *Sci. Educ.* 104, 1008–1040. doi: 10.1002/sce.21596

De Zuani, F. C., and Levrini, O. (2022). An epistemic approach to physics identity. International Research Group on Physics Teaching – GIREP 2022 Conference, 4–8 July 2022, Ljubljana.

Duit, R., Gropengießer, H., Kattmann, U., Komorek, M., and Parchmann, I. (2012). "The model of educational reconstruction - a framework for improving teaching and learning science," in *Science education research and practice in Europe. cultural perpectives in science education*, vol 5. eds. D. Jorde, and J. Dillon (Rotterdam: SensePublishers).

Emirbayer, M., and Mische, A. (1998). What is agency? *Am. J. Sociol.* 103, 962–1023. doi: 10.1086/231294

Erduran, S., and Dagher, Z. (2014). *Reconceptualizing the nature of science for science education: scientific knowledge, practices and other family categories* Springer Nature.

European Commission. (2022). Available at: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12985-Sostenibilita-ambientale-istruzione-e-formazione_it (Accessed October 4, 2022).

European Commission, Directorate-General for Communications Networks, Content and Technology, Müller, R., and Greinert, F. (2021). *Competence framework for quantum technologies: methodology and version history* Publications Office Available at: https://data.europa.eu/doi/10.2759/130432.

Fantini, P., Levin, M., Levrini, O., and Tasquier, G. (2014). "Pulling the rope and letting it go": Analyzing classroom dynamics that foster appropriation. In C. P. Constantinou, N. Papadouris and A. Hadjigeorgiou (Eds.), *E-book proceedings of the ESERA 2013 conference: science education research for evidence-based teaching and coherence in learning: Part 7. Discourse and argumentation in science education*, Nicosia: European Science Education Research Association (ESERA), 142–153.

Gee, J. P. (2000). Identity as an analytic lens for research in education. *Rev. Res. Educ.* 25, 99–125. doi: 10.2307/1167322

Ghosh, A. (2017). *The great derangement: Climate change and the unthinkable*. Berlin Family Lectures: University of Chicago Press.

Hazari, Z., Sonnert, G., Sadler, P. M., and Shanahan, M.-C. (2010). Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice: a gender study. *J. Res. Sci. Teach.* 47, 978–1003. doi: 10.1002/tea.20363

Houseal, A. K., Abd-El-Khalick, F., and Destefano, L. (2014). Impact of a student–teacher–scientist partnership on students' and teachers' content knowledge, attitudes toward science, and pedagogical practices. *J. Res. Sci. Teach.* 51, 84–115. doi: 10.1002/tea.21126

Hsiao, P.-W., and Su, C.-H. (2021). A study on the impact of STEAM education for sustainable development courses and its effects on student motivation and learning. *Sustainability* 13:3772. doi: 10.3390/su13073772

Jaber, L. Z., and Hammer, D. (2016). Engaging in science: A feeling for the discipline. *J. Learn. Sci.* 25, 156–202. doi: 10.1080/10508406.2015.1088441

Jacobson, M. J., and Wilensky, U. (2006). Complex systems in education: scientific and educational importance and implications for the learning sciences. *J. Learn. Sci.* 15, 11–34. doi: 10.1207/s15327809jls1501_4

Jacobson, S. K., Seavey, J. R., and Mueller, R. C. (2016). Integrated science and art education for creative climate change communication. *Ecol. Soc.* 21:30. doi: 10.5751/ES-08626-210330

Jones, A., Buntting, C., Hipkins, R., McKim, A., Conner, L., and Saunders, K. (2012). Developing students' futures thinking in science education. *Res. Sci. Educ.* 42, 687–708. doi: 10.1007/s11165-011-9214-9

Kapon, S. (2016). Doing research in school: physics inquiry in the zone of proximal development. *J. Res. Sci. Teach.* 53, 1172–1197. doi: 10.1002/tea.21325

Kapon, S. (2017). Unpacking sensemaking. *Sci. Educ.* 101, 165–198. doi: 10.1002/sce.21248

Kapon, S., Laherto, A., and Levrini, O. (2018). Disciplinary authenticity and personal relevance in school science. *Sci Educ.* 102, 1077–1106. doi: 10.1002/sce.21458

Kim, G., Vaswani, R. T., and Lee, D. (2017). Social-ecological memory in an autobiographical novel: ecoliteracy, place attachment, and identity related to the Korean traditional village landscape. *Ecol. Soc.* 22:27. doi: 10.5751/ES-09284-220227

Levrini, O. (2015). How can the learning of physics support the construction of students' personal identities?. GIREP-MPTL 2014 International Conference, July 7–12, 2014, Palermo.

Levrini, O., Fantini, P., Barelli, E., Branchetti, L., Satanassi, S., and Tasquier, G. (2021a). The present shock and time re-appropriation in the pandemic era. *Sci. & Educ.* 30, 1–31. doi: 10.1007/s11191-020-00159-x

Levrini, O., Levin, M., Fantini, P., and Tasquier, G. (2019b). Orchestration of classroom discussions that foster appropriation. *Sci. Ed.* 103, 206–235. doi: 10.1002/sce.214752019

Levrini, O., Tasquier, G., Barelli, E., Barelli, E., Laherto, A., Palmgren, E., et al. (2021b). 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., Barelli, E., Pucetaite, R., Rauleckas, R., Laherto, A., et al. (2023). *Pathways for a future-oriented science education pathways for a future-oriented science education – a handbook from the FEDORA project*.

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

Liao, C. (2016). From interdisciplinary to transdisciplinary: an arts-integrated approach to STEAM education. *Art Educ.* 69, 44–49. doi: 10.1080/00043125.2016.1224873

Maeda, J. (2013) STEM + Art = STEAM. *STEAM J.* 1:,:34. doi: 10.5642/steam.201301.34

Miller, E., Manz, E., Russ, R., Stroupe, D., and Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the next generation science standards. *J. Res. Sci. Teach.* 1–23. doi: 10.1002/tea.21459

Moser, S. C. (2016). Reflections on climate change communication research and practice in the second decade of the 21st century: what more is there to say? *WIREs Clim. Change* 7, 345–369. doi: 10.1002/wcc.403

OECD (2019). *OECD future of education and skills 2030: OECD learning compass 2030*, OECD Publishing, Paris. Available at: http://www.oecd.org/education/2030-project/teachingand-learning/learning/learning-compass-2030/OECD_Learning_Compass_2030_concept_note.pdf.

Paige, K., and Lloyd, D. (2016). Use of future scenarios as a pedagogical approach for science teacher education. *Res. Sci. Educ.* 46, 263–285. doi: 10.1007/s11165-015-9505-7

Pedrò, F., Subosa, M., Rivas, A., and Valverde, P. (2019). *Artificial intelligence in education: challenges and opportunities for sustainable development, [6443]*. Working papers on education policy, 7 [12], Available at: https://unesdoc.unesco.org/ark:/48223/pf0000366994.locale=en

Potvin, G., and Hazari, Z. (2014). The development and measurement of identity across the physical sciences. Physics Education Research Conference 2013, Portland, OR. 281–284.

Pucetaite, R., and Rauleckas, R. (2023). *Framework for aligning science teaching/learning in formal contexts with the modus operandi of R&I: new inter-multi-transdisciplinary forms of knowledge organisation for co- teaching and open-schooling – deliverable 1.2 (V4.0)*. Zenodo. doi: 10.5281/zenodo.7519006

Rasa, T., Laherto, A., Levrini, O., Bol, E., and Tasquier, G. (2023). *Framework to futurise science education – Deliverable 3.3 (V1.0)*. Zenodo. doi: 10.5281/zenodo.7519069

Rosa, H. (2009). "Social acceleration: ethical and political consequences of a desynchronized high-speed society" in *High-speed society: social acceleration, power and modernity*. eds. H. Rosa and W. E. Scheuerman (University Park, PA: Pennsylvania State University press), 77–112.

Rosenberg, J. M., Kubsch, M., Wagenmakers, E. J., and Dogucu, M. (2022). Making sense of uncertainty in the science classroom. *Sci. & Educ.* 31, 1239–1262. doi: 10.1007/s11191-022-00341-3

Rubin, A. (2013). Hidden, inconsistent, and influential: images of the future in changing times. *Futures* 45, S38–S44. doi: 10.1016/j.futures.2012.11.011

Satanassi, S., Branchetti, L., Fantini, P., Casarotto, R., Caramaschi, M., Barelli, E., et al. (2023). Exploring the boundaries in an interdisciplinary context through the family resemblance approach: the dialogue between physics and mathematics. *Sci. Educ.* 32, 1287–1320. doi: 10.1007/s11191-023-00439-2

Stroupe, D. (2014). Examining classroom science practice communities: how teachers and students negotiate epistemic agency and learn science-as-practice. *Sci. Ed.* 98, 487–516. doi: 10.1002/sce.21112

Stuckey, M., Hofstein, A., Mamlok-Naaman, R., and Eilks, I. (2013). The meaning of 'relevance' in science education and its implications for the science curriculum. *Stud. Sci. Educ.* 49, 1–34. doi: 10.1080/03057267.2013.802463

Tasquier, G., and Barelli, E. (2023). *FEDORA materials' effectiveness to develop thinking and future-scaffolding skills and to foster aware, responsible and proactive engagement with science: results and hypotheses from the first round implementations – deliverable 4.2 (V1.0)* Zenodo. doi: 10.5281/zenodo.7519166

Tasquier, G., Knain, E., and Jornet, A. (2022a). Scientific literacies for change making: equipping the young to tackle current societal challenges. *Front. Educ.* 7:689329. doi: 10.3389/feduc.2022.689329

Tasquier, G., Levrini, O., Barelli, E., Branchetti, L., Cullinane, A., De Zuani Cassina, F., et al. (2022b) *Report on "theoretical and pedagogical framework and design/implementation principles" – deliverable 4.1 (V3.0)*.

Troncoso, A., Conti, F., and Tola, E. (2023). *Framework for aligning science education with society: the search for new languages and narratives to enhance imagination and the capacity to talk about contemporary challenges – deliverable 2.5 (V1.0)* Zenodo. doi: 10.5281/zenodo.7519100

UNESCO (2021). *Getting every school climate-ready: how countries are integrating climate change issues in education.*

Voros, J. (2003). A generic foresight process framework. *Foresight* 5, 10–21. doi: 10.1108/14636680310698379

Vuorikari, R., Kluzer, S., and Punie, Y.DigComp (2022). *2.2: The digital competence framework for citizens – with new examples of knowledge, skills and attitudes, EUR 31006 EN*, Publications Office of the European Union, Luxembourg.

Wenger, E. (1998). *Communities of practice: Learning, meaning and identity*. New York, NY: Cambridge University Press.

Windschitl, M., Thompson, J., Braaten, M., and Stroupe, D. (2012). Proposing a core set of instructional practices and tools for teachers of science. *Sci. Edec.* 96, 878–903. doi: 10.1002/sce.21027

Wormstead, S. J., Becker, M. L., and Congalton, R. G. (2002). Tools for successful student–teacher–scientist partnerships. *J. Sci. Educ. Technol.* 11, 277–287. doi: 10.1023/A:1016076603759