FEDORA

Deliverable 4.3

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 second round implementations

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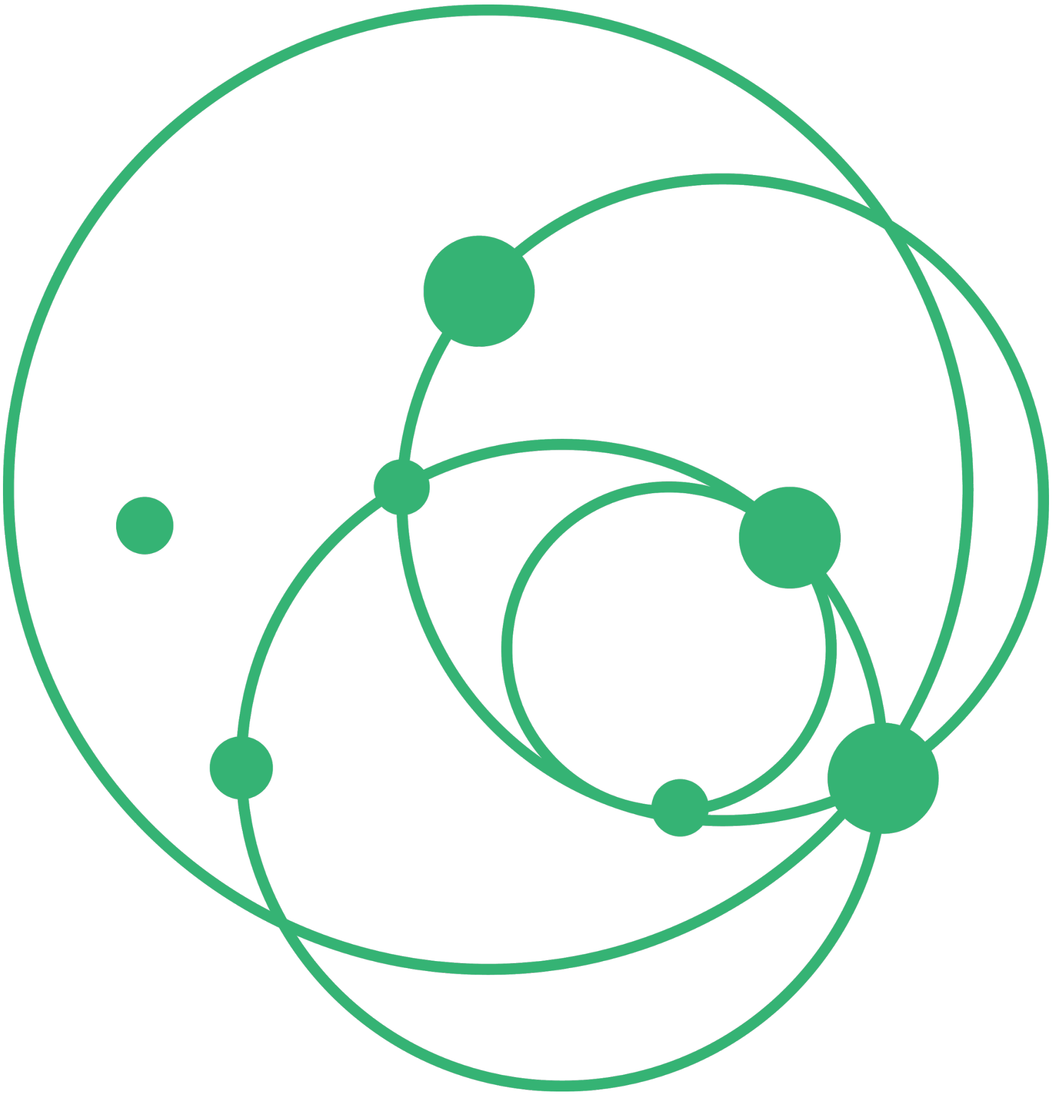
Quality assurance

To ensure the quality and accuracy of this deliverable, we employed an internal process of co-writing, review and validation process that involved some rounds of modifications. The deliverable was coordinated and finalised by the work package leader (UNIBO). UH, UNIBO and UOXF produced the sections on their implementations and all partners contributed to and reviewed the overall draft. Finally, the semi-final version was submitted to the project coordinator, for a final review and validation.

DISCLAIMER



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List of abbreviations

OSN(s)	Open Schooling Network(s)
BOSN	Bologna Open Schooling Network
HOSN	Helsinki Open Schooling Network
OOSN	Oxford Open Schooling Network
WP1	FEDORA Work Package 1: Aligning science teaching/learning in formal contexts with the modus operandi of R&I
WP2	FEDORA Work Package 2: Exploring new languages, narratives and arts in science education
WP3	FEDORA Work Package 3: Futurizing science education
WP4	FEDORA Work Package 4: Toward a model for science education for the society of acceleration and uncertainty
FR1	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
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
FR3	Framework to Futurize Science Education
SDGs	Sustainable Development Goals
MoRRI	Monitoring Responsible Research and Innovation

Introduction

This deliverable reports the state of the second and final round of FEDORA implementations as well as the results achieved by them.

FEDORA's second round of implementations took place during the third year of the project (from September 2022 to May 2023) within the three open schooling networks (OSNs) established in the developer/implementer countries (HOSN - Helsinki Open Schooling Network; OOSN - Oxford Open Schooling Network; BOSN - Bologna Open Schooling Network).

This document is an update of FEDORA's deliverable 4.2 that contained a report on the first-round implementations. Even if the two documents share many traits, this deliverable is not only a replica of the previous one. Indeed, the final round of implementation of teaching activities in the OSNs comes at the end of a three-years long process of theorization, implementation, and analysis that characterised the work within WP4 and in general all FEDORA's work-packages. In particular, the issues pointed out and the recommendations elaborated within the three frameworks on interdisciplinarity (FR1), new languages (FR2), and future (FR3), as well as the findings from the first round, served as the basis to orient the design of the final round of implementations in order to stress more and more explicitly their "FEDORA character". Concretely, this is showed in the following actions that the designer-implementer teams carried out:

- **Designing or refining resources and materials** used in the implementations in a way that they can be an inspiration for teachers and educators to design further activities on FEDORA themes for specific targets and contexts (resources for some modules are available in the project's website in the Open Schooling section);
- **Orienting the development of the teaching activities** in the light of the recommendations coming from FEDORA's frameworks and of the findings from previous implementations, as well as of other frameworks (e.g. GreenComp) **through the formulation of expected learning outcomes**;
- **Elaborating prototypes of evaluation and assessment tools, methods of observation and analysis and narratives** to check the implementations' effectiveness to develop thinking and future-scaffolding skills and to foster aware, responsible and proactive engagement with science;
- **Stressing the contribution of the findings** to address the issues or recommendations pointed out in the FEDORA's frameworks.

The deliverable is structured as follows. In the first section, we provide an overview of the second-round implementations to show the numbers of students, teachers, researchers, and other stakeholders reached, the ways in which interdisciplinarity, new languages and future were addressed, and we draft an emergent structure of the learning outcomes that oriented the design and analysis of the implementations. Then, we pass to presenting the details of the second-round implementations. In the second section, we dive deep into the findings of the implementations: we present the research questions addressed in each study, the methodology, some highlights from the analysis and their relationship with the three frameworks. Finally, in the third section, we draft some conclusions and suggestions to feed the FEDORA Model for Science Education.

Summary of the second round of implementations

In the second round, at least one implementation was carried out by each of the three OSNs, for a total of seven different implementations. Four of them were the re-edition of implementations carried out in the first round - HOSN-2023-CITY as the re-edition of HOSN-2022-CITY, OOSN-2023-MUS as the re-edition of OOSN-2022-MUS, BOSN-2023-SIM as the re-edition of BOSN-2022-SIM, and BOSN-2022-QUAN as the re-edition of BOSN-2021-QUAT (see Deliverable 4.2) - other three were totally new. In this chapter, we present the main features of the seven implementations. Specifically, in the General overview we provide a summary of the implementations, using also graphs, tables, and images. In Details on the single implementations, we present detailed information related to each implementation. To this aim, we developed a common template that was filled in by the responsible for each implementation in order to collect the same kind of information.

General overview

Seven implementations were carried out in the OSNs. In particular, one was carried out by HOSN (once), one by OOSN (repeated three times), and five by BOSN (once per type). Hence, we had seven implementations for a total of nine **repetitions**. For the sake of brevity, in Table 1 we report the identifiers of the implementations (that we will use along the deliverable) and how many times each was repeated. In this case, the repetitions, as it will be made explicit in the tables in Details on the single implementations, consist of a change of context (e.g. in-school or out-of-school context) or a change of groups of participants (e.g. repetition of the implementation with different classrooms).

Table 1. Codes, names, and the number of repetitions for each implementation.

ID of the implementation (OSN-YEAR-ID)	**Re-edition of totally new implementation**	**Extended name of the implementation**	**No. of repetitions**
HOSN-2023-CITY	Re-edition of HOSN-2022-CITY	My city of the future	1
OOSN-2023-MUS	Re-edition of OOSN-2022-MUS	Climate Change and the Future of Learning	3
BOSN-2022-AERO	New implementation	“Aerocene”	1
BOSN-2023-AI	New implementation	Artificial Intelligence (AI) Atelier	1
BOSN-2023-KAIR	New implementation	Kairos - To correct the subtle drift of days	1
BOSN-2023-SIM	Re-edition of BOSN-2022-SIM	Simulations of complex systems	1
BOSN-2023-QUAN	Re-edition of BOSN-2021-QUAT	The second quantum revolution	1

For what concerns the **contexts** of the implementations, three of them took place in-school settings (BOSN-2022-AERO, BOSN-2023-AI, BOSN-2023-KAIR), other three were conducted out-of-school (OOSN-2023-MUS, BOSN-2023-SIM, BOSN-2023-QUAN), and one of them (HOSN-2023-CITY) took place in both types of contexts. The in-school implementations are defined as such for the physical setting in which they took place and for the direct involvement of teachers of the school for the design and conduction of the implementation. The out-of-school contexts experienced in the first-round implementations consist of: i) extra-curricular courses developed in collaboration between schools and universities, ii) museums, iii) university orientation courses. All contexts for implementation were formal but that of the Oxford's Natural Science Museum (OOSN-2023-MUS).

The **time duration** of the implementations varied a lot across the OSNs, as depicted in Figure 1. They range from a minimum of 3 hours for the experience in the museum (OOSN-2023-MUS) to a maximum of 50 for the course of theatrical writing "Kairos" (BOSN-2023-KAIROS). In total, considering the repetitions of the implementations, the first round resulted in more than **130 hours** of teaching-learning experiences.

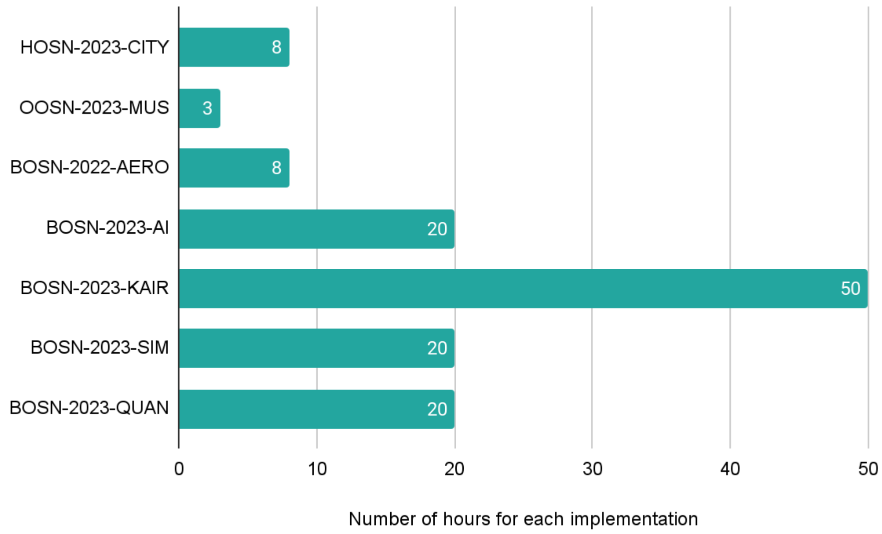


Fig. 1. Number of hours for each implementation.

All implementations were mainly targeted at **secondary-school students** (**15-19 years-old**). In total, more than **150 students** participated in the second-round implementations (89 males, 63 females, 2 identifying as them/they, 2 who did not disclose their gender); in Figure 2, we report the gender distribution of the participants. We need to stress that only for the four out-of-school implementations (HOSN-2023-CITY, BOSN-2022-AERO, BOSN-2023-SIM, and BOSN-2023-QUAN) explicit information was collected on participants' *perceived gender*, asking the participants to fill in a questionnaire without assuming their gender.

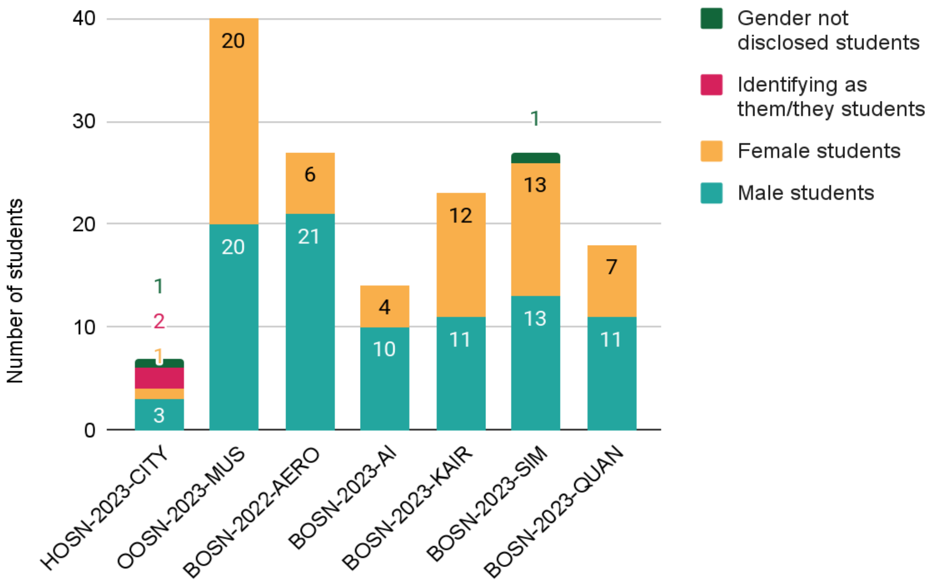


Fig. 2. Numbers of students in each implementation.

To reflect the diversity of stakeholders in all OSNs, apart from the secondary-school students, were involved in the implementations:

- 21 **in-service teachers** (10 males, 11 females);
- 18 **researchers** (5 males, 13 females);
- 8 **additional stakeholders**: two city representatives (2 females), a museum educator (female), an impact facilitator (female), three pre-service teachers (1 male and 2 females), and a creative scientist (male).

To be considered FEDORA implementations, the activities conducted address, in a variety of ways, the core issues of the project. As shown in Figure 3, the **focus on the three pillars of FEDORA** - interdisciplinarity, new languages, and future - resulted in balanced across the implementations. Indeed, each pillar was addressed by at least 5 different implementations. The most common was interdisciplinarity, which was addressed by all implementations.

Figure 3. FEDORA's pillars addressed in each implementation.

About the pillar on **interdisciplinarity** the main focal points of the implementations were:

- The focus on the complexity of real systems that involve a variety of fields of study and expertise (from the more scientific ones to the sociocultural and political ones)
- The recognition of the roles of disciplines that are studied in school curricula to tackle interdisciplinarity
- The identification of the epistemic peculiarities, constraints and potentials of different disciplines when tackling with an interdisciplinary challenge
- The widening of STEM to STEAM to include arts and humanities
- The inclusion of arts as languages that can facilitate the inhabitation of the boundaries between disciplines
- The emphasis on the interconnections of jobs and professional roles to address collective challenges

The implementations highlighted the issue of the search for **new languages** through:

- The opening-up of an imaginative and aesthetical dimension in scientific discourse
- The emphasis on arts as languages to understand and discuss global issues, avoiding trivialisations (e.g. solution-oriented discourses)
- The exploitation of artistic genres (e.g., theatrical writing, generative models for artificial intelligence art) to support science teaching and learning
- The creation of "third spaces" in-between science and arts in which experimenting with narratives to combine, mix, and acknowledge non-traditional ways of communicating

The pillar of **future** was tackled in the implementations through:

- The elicitation of students' fears and desires about personal and collective future scenarios
- The distinction between possible, probable, and desirable futures and respective strategies of envisioning them
- The exploitation of the future-oriented dimension in the epistemic structure of the scientific topics addressed
- The choice of contexts close to students' life and experience (e.g. their city, their school) for which elaborating future scenarios, in a way that they can find their own space of agency

As mentioned in the introduction, one of the main updates that this deliverable contains (with respect to the previous one on the first-round implementations) is the formulation of specific **learning outcomes** for the teaching-learning activities carried out. Indeed, they derive both from the experiences of the previous round and from the results of the three FEDORA frameworks. More generally, the statement of learning outcomes is the result of an on-going process that embraces the whole project's history, from planning to actual implementation through research and practice. Based on the information provided by the designers of the modules and fully reported in the Tables in the next section, we can categorise the learning outcomes in four areas (knowledge, interdisciplinarity, new languages, and future) and ten specific items, as reported in Figure 4.

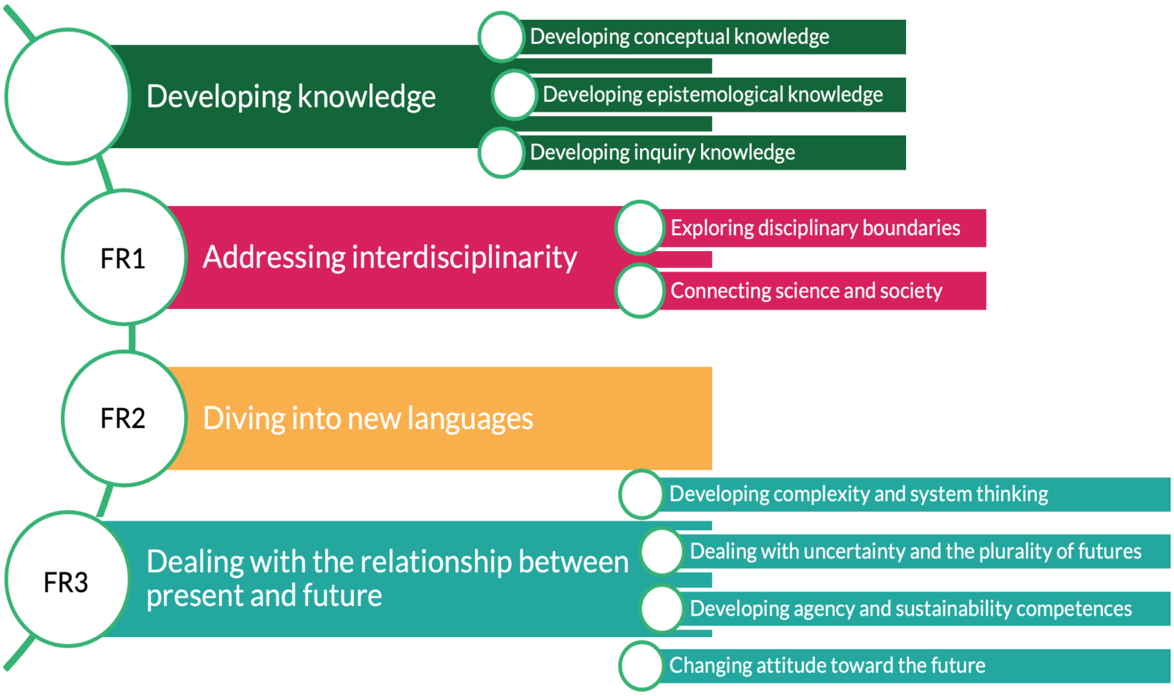


Figure 4. Clustering of learning outcomes from the second-round implementations.

In Table 2 we report examples for each category and in Figures 5 and 6 we report the match between the learning outcomes and the implementations.

Table 2. List of learning outcomes and examples from the implementations' descriptions.

Developing knowledge	Developing conceptual knowledge	Learning the **physics of aerosolar flight**: the laws that rule physical and mathematical models (first law of dynamics, Archimedes' principle, and the ideal gas law), evaluation of some construction parameters of the aerosolar sculpture that would allow its flight (temperature, number of moles...) (BOSN-2022-AERO)
	Developing epistemological knowledge	Recognizing the main **rational and epistemological aspects** that quantum physics introduces in comparison with classical physics (BOSN-2023-QUAN)
	Developing inquiry knowledge	Dealing with the **preparation and implementation of one laboratory experiment** (Bénard cells) and learning how to use the materials (hot plane, termometer) (BOSN-2023-KAIR)
Addressing interdisciplinarity	Exploring disciplinary boundaries	Being able to **recognize the interdisciplinarity** of quantum computing by **identifying the single disciplines** involved and how they **intertwined** (BOSN-2023-QUAN)
	Connecting science and society	Discussing pressing **societal issues**, values and desires **based on the discussion of a computational artefact**. (BOSN-2023-SIM)
Diving into new languages		Getting acquainted with the air, the element in which the flying structure moves, as a space of opportunity to **experiment with**

		new forms of thinking and relating science and art (BOSN-2022-AERO)
Dealing with the relationship between present and future	Developing complexity and system thinking	Developing fuller consideration of the **complexity of societal and environmental matters**, shown through increased systems thinking in terms of the topics considered during the course and their developments during the learning process (HOSN-2023-CITY)
	Dealing with uncertainty and the plurality of futures	Learning **basic concepts of futures studies** (scenarios, probable/possible/desirable futures, back-casting) and experiencing how simulations can be the basis through which implementing these concepts (BOSN-2023-SIM)
	Developing agency and sustainability competences	Evaluating how **human behaviour would have a direct impact on the environment**, and being more motivated for taking more **responsibility for what one can do** to combat climate change (OOSN-2023-MUS)
	Changing attitude toward the future	Conceptualising the **future in a more positive, hopeful manner** as compared to experiences before the course, gaining inspiration from the experts challenging their ideas as well as from the learning activities on framing mindsets towards future changes (HOSN-2023-CITY)

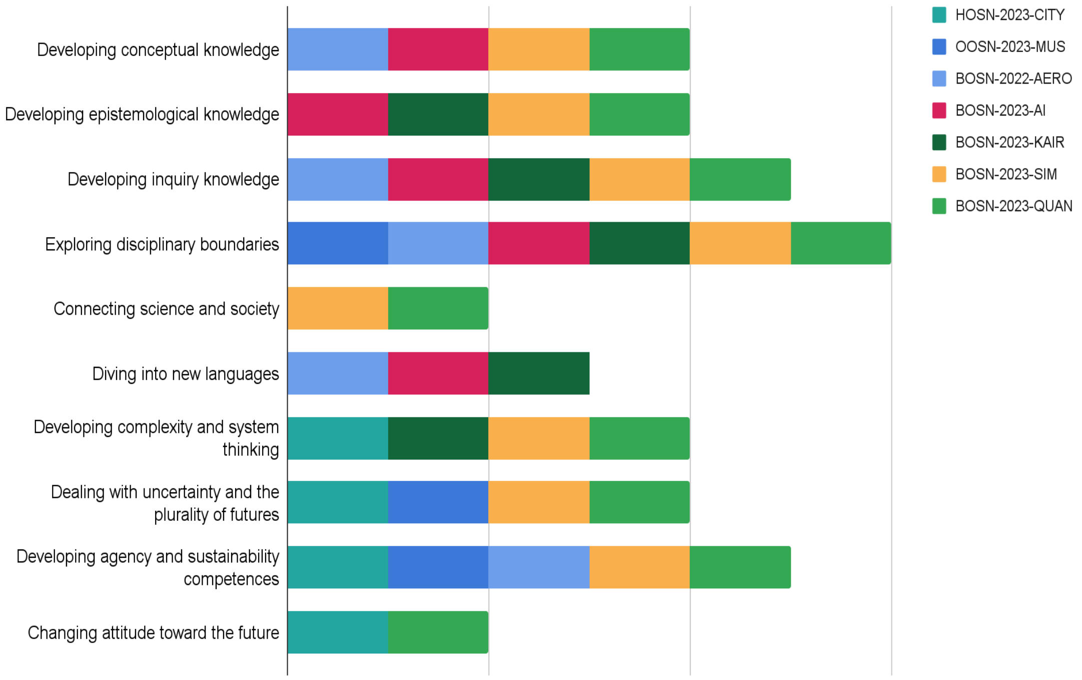


Figure 5. Implementations addressing each learning outcome.

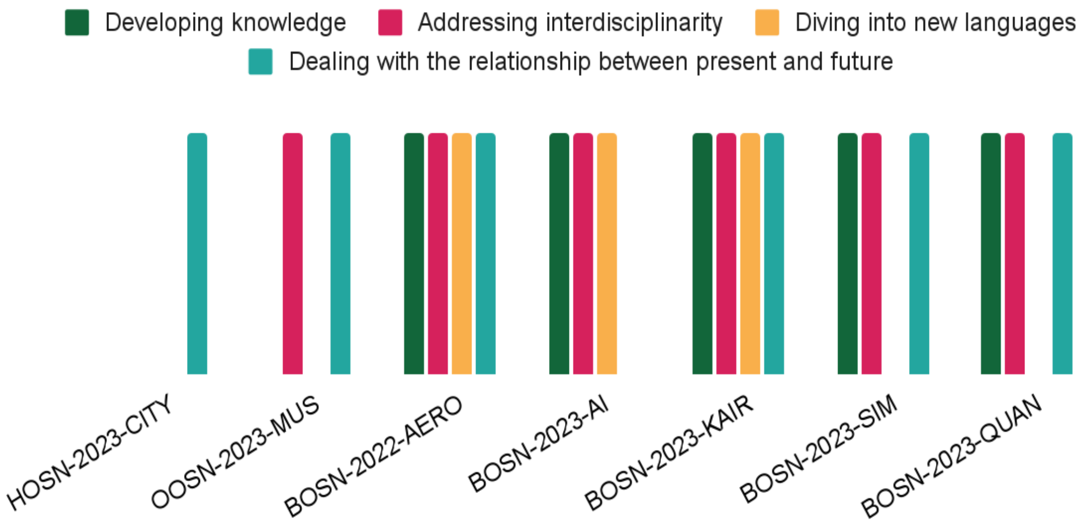


Figure 6. Areas of learning outcomes addressed by each implementation.

In particular, comparing Figure 6 with Figure 3, we notice an overall match between FEDORA's pillars addressed in the implementations and the learning outcomes.

To adhere to FEDORA's objectives, some principles to promote inclusivity at many levels were considered in the design of the implementations' learning environments. For what concerns the **enhancement of girls' self-efficacy** and the elicitation of all students' possibility to recognise a possible correspondence or superimposition between one's own **identity and authentic practices in science**, in the OSNs the actions carried out were:

- Ensuring a balanced involvement of male and female stakeholders with which the students interacted during the implementations
- Creating equal opportunities for all students to actively participate (e.g., as spokesperson)

Concerning, instead, the principles of inclusion of a **variety of forms of participations** that allow diverse students to find their own ways of participating and feeling part of classroom dynamics, the actions exploited in the implementations were:

- Designing different formats of activities with which the students engaged (e.g., individual work, collective discussions, focus groups, teamworks, workshops), both mediated and not-mediated by the instructors
- Inviting the students to take their own responsibility in teamwork activities (e.g. note-taker, reporter, technician, spokesperson)
- When the activities require collective decisions, ensuring that the opinions of all students were considered and valued in the decision-making process
- Using in the instruction a variety of disciplinary and epistemological languages to resonate with the diversity of students' epistemic stances
- Exploiting the role of artistic languages in which each student can feel allowed to contribute to the scientific theme at stake

Moving beyond FEDORA's principles to the broader level of global developmental strategy, all implementations aligned their design objectives with the **sustainable development goals** (SDGs). In particular, the main SDGs addressed were:

- **SDG 4.7** - ("by 2030 all learners should acquire knowledge and skills needed to promote sustainable development") - addressed by all implementations
- **SDG 4.3** - ("by 2030, it should ensure equal access for all women and men to affordable and quality technical, vocational and tertiary education, including university") - addressed by three implementations
- **SDG 4.4** - ("by 2030 it should be increased the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship") - addressed by three implementations.

We can remark that all implementations were (more or less explicitly) based on the idea that science is democratic and that dealing with the epistemic core of science can ensure equal access to science.

Relating to the monitoring of the quality of science literacy and science education as one of the dimensions of responsible research and innovation (RRI), FEDORA's first round implementations specifically focused on two of the four **MoRRI indicators**:

- **SLSE 1** - ("Importance of societal aspects of science in science curricula for 15-18 years old") - addressed by all implementations
- **SLSE 3** - ("Science communication culture") - addressed by four implementations.

Details on the single implementations

This section presents the details on the six implementations collected in Tables 2-7. To facilitate a comparative reading, we briefly introduce the elements of the template that was used to collect information from the leaders of the single implementations and that will be used to summarise and showcase the main features of each implementation. Specific information is given on:

- The open-schooling network and city in which the implementation was carried out
- The context, time duration and frequency of the implementation
- The number and type of participants involved
- The principles implemented in the module to enhance girls' self-efficacy and all students' participation in classroom dynamics
- The main STEM topics addressed in the implementation
- The relationship with the FEDORA pillars of interdisciplinarity, new languages and future
- The list of learning outcomes
- The sequence of activities conducted in the implementation and tools for data collection used
- The MoRRI indicators touched and the SDGs addressed

My city of the future

Table 3. Details on the implementation “My city of the future”, carried out by HOSN.

“My city of the future” (HOSN-2023-CITY)		
OSN and city	HOSN	Helsinki
Context	Mixed In-school and Out-of-school	Formal
Brief description of the context	Extra-curricular, University-school collaboration (physics / science) course at Helsinki Upper Secondary School of Natural Sciences	
Period of time and frequency	7 meetings (irregular), January-March 2023	
Total number of hours	8 hrs	
Participants	Students (16-19 y.o.): 3 males + 1 female + 2 others + 1 gender not disclosed In-service teachers: 1 male + 2 females Researchers: 2 males + 2 females City representatives: 2 females	
Collection of explicit information on the gender of the participants	Yes	
Inclusion of principles that enhance girls’ self-efficacy and students’ identity in relation to authentic practices in science	Yes. We aimed for 50-50 representation of female and male experts/policymakers/researchers that the students interacted with (close to 50-50, with slightly more females). Furthermore, all students were given equal opportunity to voice their hopes for policymakers.	
Forms of students’ participation foreseen	Yes. The students had significant autonomy in how they approached and worked with the central course tasks, and students’ outputs consequently reflected the diversity of the students.	
Choice of the scientific topics addressed	The central subject area of the course (the future of the city) emerged from a discussion with the Helsinki Open Schooling Network. We sought to meet the interests and affordances of the participating teachers while challenging ourselves to create something new based on the results of WP1-3 at the time. The OSN discussed the topic at length, recognising “the city as a system”, “energy production and carbon neutrality” and “sustainability” as interesting transdisciplinary and future-oriented lenses which the course was built around. To enhance students’ agency, futures thinking and scientific	

	expertise in policy-making were chosen as explicit topics of activities. Additional topics emerged during planning the course and recruiting guest experts; these included technology, transportation, city ecology.
Relationship with FEDORA pillars	● Interdisciplinarity (WP1): The course was explicitly transdisciplinary: the main issue was the complex system of the city, with emphasis on energy and sustainability. ● New languages (WP2): The language-widening approaches applied in the course design included discourse (especially through legitimate interaction with the city), imagination (through imaginative and strange-making activities) and so on. For example, we began the course by imagining various even bizarre futures of the city to break out of strictly logical-structural thinking. ● Future (WP3): The course, "my city of the future", was of course naturally future-oriented; the main idea of the course was to discuss the future of Helsinki. This entailed e.g. learning about and utilising concepts and methods from futures studies.
List of learning outcomes	● Students begin to conceptualise the future in a more positive, hopeful manner as compared to experiences before the course. Students gain inspiration from the experts challenging their ideas as well as from the learning activities on framing mindsets towards future changes. ● Students show deeper consideration of topics as compared to before and start of the course. They indicate fuller consideration of the complexity of societal and environmental matters, shown through increased systems thinking in terms of the topics considered during the course and their developments during the learning process. ● Students explore the implicit context of much of their actions (the city they live in) as a locus of change. Simultaneously, they explore the tacit context of the future as something to explicitly discuss. In the process, they engage in new languages of time, space and interaction. ● Students learn ways to understand and deal with uncertainty. They explore how to move from certain, hopeless futures with fixed mindsets towards more openness to alternatives and acceptance of the uncertainty of the future, whilst exploring the changes through analysis of agency and drivers of change. ● Students consider causal effects of human decisions and actions on nature and the biosphere (e.g. analysing the impact of different forms of energy production on sustainability, and understanding the infrastructural changes needed to create a more environmentally friendly future). ● Students make transdisciplinary connections between domains: for example, their societal sensemaking connects with their scientific assessments in the context of sustainability.

Brief overview of the activities implemented	1. Opening up the imagination using a modified version of the Futures Bazaar activity kit (available at https://situationlab.org/the-futures-bazaar/). Introduction into futures thinking: how it often fails to predict the future, yet one can improve and systematise one's visions e.g. by distinguishing between thinking about possible, probable and desirable futures. Beginning to work in groups on posters to "pitch" a desirable future for Helsinki in 2050. 2. Students worked on their visions for Helsinki in the year 2050, creating evocative future descriptions in small groups (in written or poster form). 3. Presenting a first draft of the poster, and then discussing with four invited consulting experts (smart city anthropology; sustainability in engineering; climate change mitigation and risk management; energy systems). 4. The students familiarised themselves with the publicly available "Carbon Neutral Helsinki 2035 Action Plan". Then they met with one of the Action Plan's authors to discuss the rationale for the environmental policies of the city of Helsinki, and ways of influencing the future of the city. A brief workshop on energy systems. 5. Meeting the consulting experts again to get final feedback on the poster drafts, with a focus on adding quantitative and systemic perspectives. 6. The course ended with a poster session and discussion between our students and a representative of Helsinki city Climate Team. Finally, we concluded with a retrospective look on the course as a whole.
MoRRI indicators touched	SLSE 1
SDGs addressed	SDG 4.7; SDG 4.3; SDG 4.4

Climate change at the museum

Table 4. Details on the implementation "Climate change at the museum", carried out by OOSN.

"Climate change and the Future of Learning" (OOSN-2023-MUS)		
OSN and city	OOSN	Oxford
Context	Out-of-school	Informal/Non-formal
Brief description of the context	Continuing from the Oxford Open Schooling Network, in Round 2 we invited three schools to participate in our one-off workshop (three workshops in total) in the Natural History Museum, Oxford. The museum is one of the University's units and has a goal in promoting science education, particularly on biodiversity and climate change to schools, the wider community and the general public. We prioritised inviting schools from disadvantaged neighbourhoods to bring benefits to the community. The workshops were delivered by Jessica, a museum educator and a research assistant. The	

	workshops consisted of a tour of the museum, researcher-led presentations, hands-on experience with the exhibits, and group discussions and presentations.
Period of time and frequency	Each school participated in one workshop in December 2022, February 2023 and May 2023. Each workshop lasted three hours in the museum.
Total number of hours	3 hours per school = 9 hours
Participants	Students (15-17 y.o.): 40 In-service teachers: 1 male + 5 females Researchers: 2 females Museum educator: 1 female Impact facilitator: 1 female
Collection of explicit information on the gender of the participants	N = 40 (from three schools) Male = 7; Female = 33
Inclusion of principles that enhance girls' self-efficacy and students' identity in relation to authentic practices in science	Yes. The design of the workshop encouraged students' voice and agency. Examples of eminent scientists included female and various racial backgrounds acting as role models for student participants. Practice in science was explained. The call for interdisciplinary collaboration from scientists was also shown in the presentation. Students were guided to link the science ideas to other subjects/disciplines in their group tasks.
Forms of students' participation foreseen	Yes. Students were given various opportunities to conceptualise and express ideas in different modalities - visual, audio, textual, tactile on museum objects, sketches, oral and graphic. The workshop was designed in a multi-modal format to facilitate a range of learning experiences. Design of the workshop, the materials used and the delivery etc. aimed at encouraging different modes of expressions from different perspectives. Students were assured that the workshop did not aim at having specific right/wrong answers so different perspectives would be strongly encouraged. In this way, creativity was one of the focuses in the delivery of the workshops. Also, the researchers (who are both expats in the host country) shared personal experiences in order to encourage students from different backgrounds to have their own voice when participating.
Choice of the scientific topics addressed	Climate change and biodiversity The topics and major themes were designed through integrating various sources of expertise: a) Input from WP1 to set up a "creative and safe space where people are welcome to experiment themselves as boundary people". b) WP2 on connecting science to other domains of knowledge; and a multi-language approach fostering transdisciplinarity. c) WP3 on anticipation-agency-reflection, openness and risk-taking. d) Results from a mini-questionnaire to experts and teachers in the

	OOSN. e) Discussions with the museum educator on the broad goals of the Natural History Museum in Oxford. f) Discussions with in-service teachers from a local school on specific topics and skills based on the school and national curricular
Relationship with FEDORA pillars	● Interdisciplinarity (WP1): Students were guided to link the science theme or ideas to other subjects/disciplines. ● New languages (WP2): How scientific messages could be communicated by artworks was presented to and discussed with students, with plenty of illustrations and examples. ● Future (WP3): Past examples of predicting the future were presented. Students were guided to imagine the future of climate change and different possible future scenarios.
List of learning outcomes	● Students imagined changes in the environment in future and other possible future scenarios (perceived future literacy). ● Students were able to see the interrelationships between science and other subjects such as geography, politics and PSHE (personal, social, health and economic education) (interdisciplinary thinking). ● Students evaluated how human behaviour would have a direct impact on the environment. At the end of the workshop, they were more motivated for taking more responsibility for what they can do to combat climate change (increased environmental agency).
Brief overview of the activities implemented	1. Introducing what is scientific research by using the Covid-19 vaccine developed by Oxford University as an example. This part is to guide students to link science and scientific research more closely to day-to-day or global problems that everyone faces. And how science communications can be mediated by socio-political discussions involving both scientists and non-scientists. 2. Introducing issues about climate change using two short videos and various data charts. This part of the activity is to cover basic understanding of climate change and to engage students to think critically about how scientific information is presented to them. Students had to complete a worksheet to consolidate their learning about the topic. The worksheet mainly covered scientific data and facts. 3. Students then shared their reactions, and to compare different ways or modals of learning about climate change. Students were also guided to think about how we can contribute to climate justice through particular personal choices. 4. "Climate change in art" was presented to students, illustrating how art communicates both information and emotion. Students were guided to imagine how artworks allow us to develop a personal relationship with the environment or scientific arguments. Such a relationship in turn motivates people to learn more about climate change and take actions. Students were invited to share their immediate feelings or emotions about those artworks. In a sharp contrast, students were presented with

	graphs and tables for data visualisation (hard facts) which are more traditional ways of presenting scientific messages. Students were then asked to reflect if the data visualisation also communicated feelings or emotions, and how effective the communication is. 5. Students explored the museum and exhibits by finding objects that connect to how they understand human impacts on biodiversity or climate change. Students sketch a drawing or write a description of the object. They then reported how the chosen object represented their personal relationship with nature and/or climate justice. 6. Students were guided to imagine future scenarios and activities, and some other consequences of those different scenarios in the future. They discussed in breakout groups and reported to the whole group afterwards.
MoRRI indicators touched	SLSE 1; SLSE 3
SDGs addressed	SDG 4.7; SDG 4.3; SDG 4.4

"*Aerocene*": elaboration on the artwork of Tomás Saraceno

Table 5. Details on the implementation "Aerocene", carried out by BOSN.

"Aerocene" (BOSN-2022-AERO)		
OSN and city	BOSN	Forlì
Context	In-school	Formal
Brief description of the context	The activity was conceived and implemented by A. Catania, B. Teodorani and A. Zanchini, respectively a Master Student of the University of Bologna and two teachers of the school. It was was organised by Baracca Institute of Forlì (Emilia Romagna), led by Maura Barnabei, as an extra-curricular course in the PCTO (Pathway for Transversal Competences for Orientation under the responsibility of A. Tedaldi e M. Maltoni) program in collaboration with the University of Bologna. PCTO (Pathways for transversal skills and orientation) are Italian national curricular projects that allow students to integrate traditional classroom training and teaching with training periods in companies or private/public institutions with which the school has an agreement, but also in school laboratories or in simulation environments. Every year the schools, also in collaboration with entrepreneurs, research institutions and universities, offers opportunities for the students to encounter the societal job needs and the frontiers of research in Science and to enrich their ideas about the impact of Science on the society we live in and what the jobs (including the jobs of scientist) can be. This experience has been carried out officially in collaboration with the Aerocene project of Tomas Saraceno and the Aerocene community that has been establishing:	

	https://aerocene.org/flying-with-aeronatutical-students-in-forli-italia/. It was observed and investigated by the master student A. Catania in collaboration with the research group of the University of Bologna (O. Levrini, G. Tasquier, P. Fantini,, S. Satanassi).
Period of time and frequency	2022 November and December (+ the last meeting in January 2023)
Total number of hours	8 hrs, divided in 4 extra-curricular meetings + a final activity
Participants	Students (16-17 y.o.): 21 males + 6 females In-service teachers: 2 males + 1 female
Collection of explicit information on the gender of the participants	Yes
Inclusion of principles that enhance girls' self-efficacy and students' identity in relation to authentic practices in science	No
Forms of students' participation foreseen	Yes. Different forms of participation were set up such as collective discussions, focus groups, and teamwork activities, inverted classes to promote collaboration among peers.
Choice of the scientific topics addressed	The choice of the topics was related to the school's goals of rethinking curricular scientific topics to better grapple with environmental issues and contribute to developing the competencies outlined in the Greencomp. The school is an Aeronautical technical school, attended by students coming from all over the Country because of their passion for flying. The school has recently designed a vertical interdisciplinary curriculum to regenerate disciplines for pursuing the goal of education to sustainability. Being a technical school, art is not part of the curriculum. Thus, this specific module, elaborated in collaboration with FEDORA, was designed to investigate the cultural and educational potential of the interdisciplinarity between art and science to enhance imagination, equip teachers, teacher trainers, and their students with linguistic, argumentative, and imaginative skills needed to better grapple with current challenges. The course was co-designed starting from the artworks of Tomás Saraceno, in particular the Aerocene backpack. As stressed in the website of the Aerocene project (https://studiotomassaraceno.org/), This artwork embodies the artist's aim of devising new modes of ecological sensitivity, reactivating a common imaginary toward an ethical collaboration with the atmosphere and the environment, in an era free from borders, free from fossil fuels. The Aerocene sculpture, which aims to break with the current geological era (Anthropocene), emphasises the artistic and scientific exploration of

	environmental issues and stimulates common links between social, mental, and physical ecologies. The curricular topics at the basis of the course, which leads to the co-construction and the flight of the Aerocene backpack, are a critical analysis of the first law of dynamics, Archimedes' principle, and the ideal gas law (Viennot, 1998). The artwork of Saraceno provided the chance to build a school activity where the relationship between art, science, and technology was analysed within a vertical curriculum on climate science and "the dream to fly".
Relationship with FEDORA pillars	● New languages (WP2): The Aerocene course was designed around Saraceno's artwork of the "Aerocene backpack" that was borrowed for two months, thanks to the participation of the school to the open project of the artist (https://aerocene.org/flying-with-aeronatutical-students-in-forli-italia/). The realisation and analysis of the artwork gave the chance to activate reflections on the need to search for new interdisciplinary languages to talk about environmental issues. Inspired by the artwork, the students were guided to unpack the several meanings embedded in the entire work of Saraceno and to recognize "what science" there is behind the "Aerosolar sculpture", "what art" there is behind, and which boundary zone is created by the artwork,, highlighting how art can explore and contribute to key issues around climate change and environmental justice. ● Interdisciplinarity (WP1): Thanks to the analysis of the work of Tomás Saraceno the nexus between art, science, and technology has been analysed from a sustainability perspective. ● Future (WP3): Saraceno's concept of Aerocene, compared to the concept of Anthropocene, stimulated the students to imagine possible and desirable future scenarios in which the relationship between nature, humans, science, and technology is refounded for a more sustainable world.
List of learning outcomes	● Learning the physics of aerosolar flight: the laws that rule physical and mathematical models (first law of dynamics, Archimedes' principle, and the ideal gas law), evaluation of some construction parameters of the aerosolar sculpture that would allow its flight (temperature, number of moles…) ● Getting acquainted with the science and technique of flight through practical and laboratory activities based mainly on learning-by-doing. ● Getting aware that there exists an important debate within the arts on fostering imagination toward a more sustainable future and getting acquainted with the "philosophy" of Tomás Saraceno, his languages and narratives between visual art and science for envisioning new futures ● Getting acquainted with the geological era of Anthropocene and getting introduced to Saraceno concept of "Aerocene" ● Opening a new creative perspective to think on the air, the element in which the flying structure moves, as a space of opportunity to

	experiment with new forms of thinking and relating ● Dealing with sustainability in terms of i. Embodying sustainability values ii. Embracing complexity in sustainability iii. Envisioning sustainable futures iv. Acting for sustainability.
Brief overview of the activities implemented	The activity consists of 6 meetings. It starts with the presentation of the activity, its goals, and the main contents. The first fart of the meeting concerned the introduction of climate issues: the Anthropocene era, climate change as complex issues, its interdisciplinary features and analysis of the causes; the IPCC future scenarios). The second part concerned art and its possible role in dealing with climate issues. In particular, the students were introduced to the debate on the definition of artwork, the artistic glance as a special perspective to look at current issues from a different perspective. A special focus was made on the philosophy and artworks of Saraceno, the "Aerocene project" and its link with climate issues: a vision of a future free from fossil fuels, free from national borders and free from the logic of indiscriminate exploitation of natural resources. In the second meeting, students were introduced to the physical principles that enable aerosolar flight and to the laboratory activity of building a prototype of the aerosolar activity. In the third meeting, students were engaged in the construction of the aerosolar sculpture following the artist's tutorials (https://aerocene.org/tools-and-applications/), in the investigation and evaluation of the parameters, and in the identification of the correct procedure that allows the sculpture to fly. This activity paved the way to explore the boundary zone between art and science. On the last day, students were engaged in the construction of the sculpture with the materials that the Aerocene Foundation provided to the school. In the last meeting, which involved all the school, the students flew the sculpture.
MoRRI indicators touched	SLSE 1; SLSE 3
SDGs addressed	SDG 4.7; SDG 4.3; SDG 4.4

Artificial Intelligence Atelier

Table 6. Details on the implementation "AI Atelier", carried out by BOSN.

"Artificial Intelligence Atelier" (BOSN-2023-AI)		
OSN and city	BOSN	Rimini
Context	In-school	Formal
Brief description of the context	The course was organised by the Liceo Scientifico Einstein as an extracurricular activity in collaboration with the University of Bologna. The AI atelier is part of the PCTO project. PCTO (Pathways for transversal skills and orientation) are Italian national curricular projects that allow students to	

	integrate traditional classroom training and teaching with training periods in companies or private/public institutions with which the school has an agreement, but also in school laboratories or in simulation environments. Every year the schools, also in collaboration with entrepreneurs, research institutions and universities, offers some opportunities for the students to encounter the societal job needs and the frontiers of research in Science and to enrich their ideas about the impact of Science on the society we live in and what the jobs can be. The AI Atelier was conceived and implemented by M. Giuseppucci, M. Clementi, P. Fantini, F. Filippi (teachers of the school), and it was observed and investigated by the group of the University of Bologna (E. Barelli, I. Molinari, S. Satanassi).
Period of time and frequency	March-April 2023
Total number of hours	Approximately 20 hours
Participants	14 Students (10 males and 4 females) 5 In-service teachers (2 females and 3 males) 2 researchers (female) 1 Master student (female)
Collection of explicit information on the gender of the participants	No
Inclusion of principles that enhance girls' self-efficacy and students' identity in relation to authentic practices in science	No
Forms of students' participation foreseen	Yes. Different forms of participation were set up such as frontal lessons, collective discussions, teamwork, and individual activities. Different kinds of activities both in terms of format and content (art, philosophy, ethics, ...) were developed to make as many students as possible feel at ease as well as include different tastes. Students in groups or individually were engaged in the design and production of artworks that involved the exploration and the use of open AI resources like ChatGPT, DALL.E, and MidJourney. In the design and production of the artworks, students were asked to choose a theme that they felt strongly about and re-elaborate it in an artistic way through their favourite or more suitable artistic language (visual art, sound art, performances, writing, and texts...).
Choice of the scientific topics addressed	The AI Atelier was designed on the comparison between human and artificial creativity with the aim of making students reflect on the digital society in which we are immersed today. The core topics were machines and their

	working mechanisms, the differences between symbolic and connectionist approaches, neural networks, the latest generative systems based on deep learning, and the similarities and differences between humans and artificial creative processes as well as between human and artificial thinking. The creativity of AI compared with the creativity and artistic thinking of humans became the context to reflect critically on the limits and the potential of AI and on new possibilities to conceive the relationship between man, science, and technology in a sustainable way (from an ethical, social, educational, ets., perspectives.).
Relationship with FEDORA pillars	● Interdisciplinarity (WP1): Interdisciplinarity between art, philosophy, and science is at the basis of AI Atelier. In particular, the course revolves around the comparison between humans' creativity and artistic thinking on the one hand and "artificial creativity" and generative algorithms on the other. This intertwining becomes the context in which to touch on philosophical and ethical aspects such as the similarities and differences between humans and artificial thinking, human-machine hybridization, and the potential and limits of artificial intelligence. ● New languages (WP2): The atelier was co-designed to create an open and collaborative space in which to develop new languages to enhance the imagination and the ability to talk about contemporary challenges by supporting young people to build visions of the future that give strength to actions in the present. In particular, the theme of the design of new languages is the cornerstone of the laboratory work carried out during the course. The students, "interweaving" human creativity and "artificial creativity", developed artwork through the use of some generative machine learning algorithms like ChatGPT and MidJourney, and then they presented in a final event to the whole school.
List of learning outcomes	● Learning the basics of machine learning generative models; ● Understanding the peculiarity of symbolic, connectionist, and sub-symbolic approaches of AI and their epistemological meanings; ● Reflecting on what it means for humans and machines "to think", stimulated by philosophical reflections; ● Reflecting on significant cases in the history of visual arts in which the concept of the citation was exploited in a particular manner; ● Experimenting with machine learning generative models to elaborate an artistic work; ● Reflecting on the relationship between science and technology and arts; ● Reflecting on the condition of being digital natives, the potential and the critical aspects of the AI today; ● Acquiring awareness and critical thinking about contemporary society and orienting themselves toward a more sustainable relationship between technology, science, nature, and humans.
Brief overview of the activities implemented	The course was divided into three phases. During the first phase, students were guided to reflect on the relationship between artificial intelligence, creativity, and art. The discourse started from the analysis of some exemplary

	results of human creativity in the artistic field and others generated artificially. The proposed examples were intended to characterise what it means to create/think for humans on the basis of some hypotheses highlighted over the course of centuries of philosophical and critical aesthetic reflections in constant comparison with artificial processes as we know them today. In a subsequent phase, the students were invited to re-elaborate the concepts that had most struck them in an artistic and creative way to implement their creative ideas. The laboratory was managed in order to gradually fine-tune the ideas in terms of conceptual clarity with respect to the theme of the Atelier and the scientific correctness of the knowledge concerning artificial intelligence systems. In the last phase, students were asked to write texts about their artwork and the workshop experience and to present their works to the school at a final event.
MoRRI indicators touched	SLSE 1; SLSE 3
SDGs addressed	SDG 4.7; SDG 4.4

Kairos - To correct the subtle drift of days

Table 7. Details on the implementation "Kairos - To correct the subtle drift of days", carried out by BOSN.

"Kairos - To correct the subtle drift of days" (BOSN-2023-KAIR)		
OSN and city	BOSN	Rimini
Context	In-school	Formal
Brief description of the context	The course is framed within the collaboration between the Bologna group of research and the Liceo Einstein The main goal of the collaboration is to regenerate disciplinary knowledge at school, so as to make it open, interdisciplinary, and connected to societal challenges. The teachers involved in Kairos are an Italian literature in-service teacher and a physics retired teacher; these teachers did a similar activity two years ago, also in collaboration with the Bologna research group, of which the physics teacher has been part since about 15 years ago. The idea at the basis of the activity was inspired by the collaboration of the physics teacher with the research group,, but the materials have been developed and implemented by the two teachers (S. Moresco and P. Fantini). The course has been done within curricular hours, mainly within the Italian literature ones, but including activities and topics that are traditionally not included in the curriculum. The implementation was observed and analysed by F. De Zuani Cassina (PhD student), V. Ilari (Master student) under the supervision of O. Levrini.	

Period of time and frequency	March 2023-May 2023 (at least once a week)
Total number of hours	Approximately 50 hours
Participants	Students: 11 males + 12 females In-service teachers: 2 males + 1 female Researchers: 1 male + 1 female Master student: 1 female
Collection of explicit information on the gender of the participants	No
Inclusion of principles that enhance girls' self-efficacy and students' identity in relation to authentic practices in science	The entire module was thought from the beginning as a chance to enhance students' participation and self-expression. The overall aim of Kairos was to turn disciplinary curricular knowledge into a scaffolding that could guide the students to navigate the contents, according to their personal interests and tastes.
Forms of students' participation foreseen	Yes. Different forms of participation were set up such as frontal lessons, collective discussions, teamwork, and individual activities. Different kinds of activities both in terms of format and content (literature, physics, chemistry,...) were developed to make as many students as possible feel at ease as well as include different tastes. The final goal of the activity was to write a theatre piece on the different faces of time. Each student was asked to write a scene, each group one act and the whole class the piece. This structure implied different forms of collaboration and teamwork.
Choice of the scientific topics addressed	The course focuses on time and its multiple nuances; borrowing from the ancient Greek tradition, four kinds of times were at the core of the activity: kairos (the time of the chance), *aion* (the eternal /absolute time), *eniautos* (the circular time) and *cronos* (the linear time). This choice is informed by analysis outcomes already published in a previous paper, where it was seen that dealing with time is a crucial issue for students; they feel the presence of an *external* time which is different from their *internal* time, and matching the two forms of time is more and more complicated in the society of acceleration (Levrini et al., 2021). Given this, the four faces of time were presented through the mediation of the Physics of Complex Systems, which was used as a context since it contains many references to the four Greek kinds of times. The four faces of the time were also the main content of a task of creative writing: the students, in group, were asked to write a theatre piece where the faces of time were represented.
Relationship with FEDORA pillars	● Interdisciplinarity (WP1): The activity is built to make science (physics) dialogue with Italian literature and foster interdisciplinarity between

	scientific and humanistic disciplines. ● New languages (WP2): The activity is based on guiding the students to writing a text (theatrical piece) with a scientific theme as a scaffolding for the scene's meaning and structure. This requires bringing the constraints of physics and those of creative writing into play.
List of learning outcomes	Students got acquainted with: ● Learning the meaning of complex system and the basic concepts of the science of complex systems: circular causality (positive and negative feedbacks), deterministic chaos, unpredictability, emergent properties, the role of agents' interactions, bifurcations, temporal and spatial patterns, irreducibility, self-organisation ● Learning the role of science of complex systems in the current society and why it can be a relevant sources of knowledge to address societal phenomena ● Learning how to set and conduct an experiment with new materials (Bènard cells) ● Learning what NetLogo simulations are and how they can be used to explore questions by "playing" with simulations' parameters ● Learning about the structure and the forms of theatre works; ● Developing narratological and linguistic skills by engaging in creative writing sessions ● Developing interdisciplinary attitude and skills to both recognise and overcome disciplinary boundaries ● Appropriating scientific and literature contents by engaging in a workgroup activity of creative writing (a theatre piece) ● Learning to see themselves as members of a complex society, made of linear and circular relationships ● Exploit the creative writing as a training for divergent thinking
Brief overview of the activities implemented	The module consists of about 50 hours, articulated in different types of activities. In the first 2 lectures the physics teacher introduced the basic concepts of physics of complex systems, such as feedback effects, the difference between *complex* and *complicated*, the meaning of interactions between agents, the meaning of the scale size (micro-macro), the self-organisations of the agents. Besides concepts' explanation, the teacher explicitly and systematically highlighted the epistemic practices that scientists use to make sense of these phenomena and deal with their explanation, reporting how these can be considered lenses by which it is possible to read other situations that appear as complex. In these lectures, students also explored the meaning of these concepts by playing with NetLogo simulations. In the third lecture two laboratory experiments have been done: - Bènard cells: students realised, with the help of the in-service physics teacher, the experiment of Benard cells. A liquid (silicon/olive oil) is heated by a hot plate, until it displays a cell structure. - Periodic chemical reaction: with the lab-technicians and the

	chemistry professor, students attended the realisation of a chemical solution (sodium tartrate, hydrogen peroxide, copper sulphate) which displays a periodic change of colour when stationarily stirred. After the first part of the module, the module shifted to the writing and to build the interdisciplinary zone. The first lesson in this second part was interactive and co-taught: the physics teacher and the literature teacher showed a bridge which connects the concepts of complexity with ideas of literature. Specifically, they unpacked the concept of time, using the 4 Greek kinds: *kairòs*, *eniautòs*, *aiòn*, *krònos*. Furthermore, the literature teacher borrowed from the literature domain the Pirandello concept of humoristic/comic and explained how this is connected to the questioning of causality, a concept also questioned by feedback effects in physics. After this lecture, in the following lectures students started the creative part. They were divided into groups, and let free to discuss and make choices about the writing, and over many sessions they wrote the scenes. These lectures have been done during both curricular hours and at home, over April and May 2023; the classroom writing sessions were monitored by one of the two teachers involved, who played the role of guide. S The final outcome was to write a theatre pièce made of 5 acts, each of which was assigned to a group of students; in doing so they were also asked to respect specific narratological constraints and to deal with the different temporalities introduced in the first physics lectures.
MoRRI indicators touched	SLSE 1
SDGs addressed	SDG 4.7; SDG 4.4

Simulations of complex systems

Table 8. Details on the implementation "Simulations of complex systems", carried out by BOSN.

"Simulations of complex systems" (BOSN-2023-SIM)		
OSN and city	BOSN	Bologna
Context	Out-of-school	Formal
Brief description of the context	This implementation was situated in the context of the Italian national program that aims at orienting high school students to the choice of a scientific university course (PLS – Progetto Lauree Scientifiche, Scientific Degrees Project). The Department of Physics and Astronomy of the University of Bologna offers every year a variety of opportunities for the students to encounter the frontiers of research in Physics and to enrich their ideas about what the jobs of physicists can be. The module was designed and implemented by E. Barelli (post-doc) in	

	collaboration with Daniele Bonacorsi and Giannandrea Inchingolo who carried out some lectures and activities within the module. It was observed and investigated by E. Barelli, under the supervision of O. Levrini.
Period of time and frequency	2023 February-March, once a week
Total number of hours	18 hours in presence + 2 of asynchronous activity
Participants	Students (16-19 y.o.): 13 males + 13 females + 1 prefer not to say In-service teacher: 1 male Researchers in science education: 2 females Full professor expert in computational physics: 1 male Creative scientist: 1 male
Collection of explicit information on the gender of the participants	Yes
Inclusion of principles that enhance girls' self-efficacy and students' identity in relation to authentic practices in science	No
Forms of students' participation foreseen	Yes. In all group activities, the students were invited to take their own responsibility with respect to a specific task (e.g. take notes, report to the whole group, manage the technological issues, keep contact with instructors, …), so that everyone was part of the group dynamics. In specific parts of the project, when decisions had to be made by the group, students were encouraged to listen to everyone's opinion and then vote for the preferred one. In general, also during lectures, the instructors took care of using a variety of languages (also disciplinary ones: e.g., physical modelling, mathematical formalism, computational implementation, the domain-specific characteristic of the system under study, the artistic language) to make as many students as possible feel at ease.
Choice of the scientific topics addressed	The module is focused on computational simulations. These advanced tools that nowadays characterise the methods of research and innovation are framed within the wider paradigm change brought by the data revolution and data-intensive methodologies that invest not only the STEM disciplines but also the social sciences and the arts. In particular, the module is focused on agent-based simulations as methods that can be used to model complex systems that consist of many individual components that interact among each other and with the environment. Agent-based simulations are analysed from a conceptual and computational point of view for their key role of embedding mechanisms of interaction, properties of the agents and emerging features of

	the systems, and for their use to elaborate possible future scenarios. By exploiting analogical reasoning, the students are guided to recognize that simulations originally formulated to model predator-prey interactions or the behaviour of magnetic materials can be applied to model societal situations like the behaviour of economic markets and opinion dynamics.
Relationship with FEDORA pillars	● Interdisciplinarity (WP1): the object of computational simulation lies at the interface between physical modelling, mathematical formalisation, and computational implementation but also social sciences; hence, it can be characterised as an interdisciplinary "boundary" object. ● Future (WP3): simulations have a future-oriented character since they allow to perform experiments in a virtual laboratory in which many possible scenarios of future evolution of many types of systems can be obtained; the future-oriented character of simulations is mirrored in a series of activities of scenarios' construction based on simulations that aims at enhancing students' imagination toward the future through science education.
List of learning outcomes	● Learning the basic concepts of complex systems and computational simulations; ● Exploring the applications of simulations in STEM and other areas of knowledge; ● Understanding the conceptual and epistemological difference between equation-based and agent-based modelling; ● Interpreting simple agent-based models, their assumptions, the mechanisms they embed, the properties of the agents, the parameters that can be changed, the scenarios that can be obtained; ● Being able to extend a simple model to a different application context through the exploitation of conceptual analogies, also pointing out limitations and potentials of the analogy; ● Learning basic concepts of futures studies (scenarios, probable/possible/desirable futures, back-casting) and experiencing how simulations can be the basis through which implementing these concepts; ● Discussing pressing societal issues, values and desires based on the discussion of a computational artefact. ● Recognizing the role of humans for the future evolution of systems and their sustainability ● Develop future-scaffolding skills to construct systemic pictures of the present and navigate the uncertainty of the future
Brief overview of the activities implemented	The module consists of about 20 hours, articulated in different types of activities. From the beginning, students are introduced to the main pillars of the module: interdisciplinarity and future, both reflecting on the complex intertwining between science and society. The module starts with an overview lecture on computational science in the era of big data. Then, activities are conducted to make students experience the variety of researches that can be carried out based on simulations: in this

	implementation, a "creative scientist" was involved to present his research work in the field of astrophysics that implies art for creating immersive experiences; after his talk, the students experienced the simulations using VR apparatus. Special time is then dedicated to exploring interactively with students some agent-based simulations in Netlogo, by pointing out the features of the models they embed (from a physical, mathematical, and computational perspective) and the scenarios they produce. To bridge the scientific models to societal applications, an activity is carried out to make students develop analogies between the previously encountered simulations and real societal issues. After a presentation on the main concepts and vocabulary of futures studies, the last activity of the module asks the students to work in a group to work on a simulation to elaborate possible and desirable future scenarios for the school of the future and to outline possible actions to be undertaken to achieve the preferred one.
Types of data collected and tools	• Focus group protocol to develop future scenarios based on simulations • Final interview protocol • Final evaluation questionnaire
MoRRI indicators touched	SLSE 1; SLSE 3
SDGs addressed	SDG 4.7; SDG 4.3; SDG 4.4

The second quantum revolution

Table 9. Details on the implementation "The second quantum revolution", carried out by BOSN.

"The second quantum revolution" (BOSN-2023-QUAN)		
OSN and city	BOSN	Bologna
Context	Out-of-school	Formal
Brief description of the context	This implementation was situated in the context of the Italian national program that aims at orienting high school students to the choice of a scientific university course (*PLS – Progetto Lauree Scientifiche*, Scientific Degrees Project). The Department of Physics and Astronomy of the University of Bologna offers every year a variety of opportunities for the students to encounter the frontiers of research in Physics and to enrich their ideas about what the jobs of physicists can be. The module was designed and implemented by S. Satanassi (post-doc) in collaboration with Elisa Ercolessi, Paola Fantini and Francesco Minardi who carried out some lectures and activities within the module. It was observed and investigated by S. Satanassi (postdoc), under the supervision of O. Levrini.	
Period of time and frequency	January-February 2023	

Total number of hours	18 hours in presence + 2 of asynchronous activity
Participants	Students (17-18 y.o.): 11 males + 7 females Pre-service teachers: 1 male + 1 female Researchers: 1 male + 2 females
Collection of explicit information on the gender of the participants	Yes
Inclusion of principles that enhance girls' self-efficacy and students' identity in relation to authentic practices in science	No
Forms of students' participation foreseen	Yes. Different forms of participation were set up such as frontal lessons, collective discussions, focus groups, and teamwork activities. In all group activities, the students were invited to take their own responsibility with respect to a specific task (e.g. take notes, report to the class, keep contact with instructors, ...), so as to be part of group dynamics. In specific parts of the project, when decisions had to be made by the group, students were encouraged to listen to everyone's opinion and then vote for the preferred one. Different kinds of activities both in terms of format and of types (conceptual-epistemological, future-oriented, and citizenship activities) were developed to make as many students as possible feel at ease as well as include different tastes and kinds of reasoning.
Choice of the scientific topics addressed	The course focuses on the Second Quantum Revolution and the emergent technologies that have been developing. Starting from the idea of valuing the Nobel Prize 2022 assigned jointly to Alain Aspect, John Clauser, and Anton Zeilinger for their experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science, the course is designed to point out the foundational and epistemological aspects of the two quantum revolutions, the experimental challenges and the implications of these on research, politics, economy, society, education, ethics, environments and so on. The passage to quantum technologies and, in particular, to quantum computation and information is another key aspect of the course and it is based on the idea that every natural phenomena can be codified on a computational basis and can be processed to solve problems and tasks. We mainly focus on quantum algorithms and quantum protocols such as the BB92 cryptography protocol and the teleportation one because of their educational relevance (they are within the reach of upper secondary school students, they highlight and embody the intrinsic interdisciplinarity of the theme and research and they can be placed in larger discussions to investigate political, economics, and societal implications of these).

	The course and the activities do not aim only to touch the content and dimension of the present. They also aim to touch on the future dimension. To reach this, the idea of scenario, foresight, futures, the Voro's cone are introduced as concepts and contexts in which reconceptualize the epistemic structure of quantum physics. In particular, we reconceptualize the concept of probability and different measurement outcomes as the possibilities of imagining probable, possible, and desirable futures, the idea of manipulation as agency and action to reach the desirable future.
Relationship with FEDORA pillars	● Interdisciplinarity (WP1): The theme of interdisciplinarity is the matrix of the course. Quantum technologies are a STEM topic and, throughout the course, the activities are designed to touch on the nature of the disciplines (in particular physics, computer science, and mathematics) and their intertwining as a way to include different personal students' interests and tastes as well as to develop interdisciplinary skills. ● Future (WP3): The idea of the quantum state as a superposition of possible states, the measurement, the idea of state manipulation, the nature of probability, and the concept of randomness characterises the epistemic structure of quantum physics and quantum computation as a source of words, a vocabulary, to deal with the complexity of the present as well as to think and develop an attitude toward futures. These concepts can be reconceptualized through the futures cone and within futures studies, promoting the development of future thinking, contingencies management, and probabilistic thinking.
List of learning outcomes	● Learning the basic concept of quantum physics; ● Learning what quantum technologies, and what the connected fields of research are; ● Being able to recognize the interdisciplinarity of the theme by identifying the single disciplines involved and how they intertwined; ● Reflecting on the role and the impact of quantum technologies on the dimensions of research, society, politics, economy, environment, ethics, and so on. ● Recognizing the conceptual, epistemological, experimental, and cultural revolutionary aspects that characterise the first and the second quantum revolution; ● Recognizing the main rational and epistemological aspects that quantum physics introduces in comparison with classical physics; ● Dealing with the new conception of probability in quantum physics as a lens to interpret the contemporary society and dealing with uncertainty; ● Being able to think out of the box and developing creativity, figuring out how the main revolutionary aspects can impact and be reconceptualized in other contexts; ● Learning the basic concepts of future studies (scenarios, probable, possible, desirable futures) and reflecting on the link between them and the epistemic structure of quantum physics as a vocabulary source. ● Applying the concepts of future studies and probabilistic thinking to reflect and build desirable futures.

	• Being able to share values, aims, dreams, and visions of futures to co-design and co-build the society that students desire to live in.
Brief overview of the activities implemented	The course consists of 6 meetings of 3 hours each organised in lectures, teamwork activities, and collective discussions. After an introduction to the course, its general objectives and values, the FEDORA project and its themes, and the different types of activities in which students were involved, we introduce the first (first day) and second quantum revolution (the second day) in order to highlight the revolutionary aspects from a cultural, conceptual, epistemological and experimental perspective and introducing the concepts of the quantum state, state manipulation/evolution, and measurement and entanglement. Then, we move from the physical and epistemological dimension to the computational one by introducing quantum computation and the transition to information by leveraging the revolutionary idea of codifying the natural world on a computational basis (third day). Furthermore, in this meeting, students are asked to reflect on the paradigm shift and the main characteristics of quantum physics in comparison to classical. This is done using the figure of the demon, especially the Laplace demon, to recognize the space-time structure and the idea of prediction in the classical case and is then asked the students to try to write the quantum demon reasoning about how the categories of space-time and prediction in the quantum case change. In the following meetings, students are introduced to some pivotal protocols and algorithms at the basis of key quantum technologies, in particular cryptography and teleportation protocols. Furthermore, in these meetings, the concepts of scenario and probable, possible, and desirable futures are introduced and the Voros' cone is used to reconceptualize and "widen" the meaning of concepts previously learned (quantum state, state manipulation/evolution, and measurement and entanglement). In the last meeting, students in groups made a scenario-building exercise and presented their work and process of building to the class.
MoRRI indicators touched	SLSE 1; SLSE 3
SDGs addressed	SDG 4.7; SDG 4.3; SDG 4.4

Results on materials' effectiveness to develop thinking and future-scaffolding skills and to foster aware, responsible and proactive engagement with science

As we can see from the presentation, the implementations present a good level of diversity able to cover all the main themes of the project. In this chapter, we provide an overview of the main research questions that guided the implementations, the main methodologies used, and the highlights of the preliminary results. In the presentation of the results, specific attention is devoted to pointing out the relationship of the findings with the three FEDORA frameworks on interdisciplinarity, new languages and future, the issues raised and the recommendations developed[1].

Research questions addressed

On the basis of the results of the first-round implementations and in the light of the three FEDORA frameworks, RQs for each study were progressively refined. Table 10 includes the main RQs addressed by each second-round implementation. We highlight with different colours some keywords related to the key area of interest identified in the research agenda: Interdisciplinarity (*in terms of construction of shared space and dialogue between disciplines, interdisciplinary skills, …*), Future (*in terms of future literacy and culture, futures stories and imagination, scenario-based teaching, future-scaffolding skills, …*) New Languages (in terms of *future story-telling and imagination, verbalising skills, identifying disciplinary and interdisciplinary languages, contamination between scientific language and other languages - like art and movie*), Agency and Epistemic emotions.

Table 10. Overview of the specific RQs addressed in the second-round implementations.

HOSN-2023-CITY "My city of the future"	● How did the students develop future thinking skills through the module (e.g. coping with uncertainty, sensemaking and strangemaking)? How were these skills exhibited by the students? ● How can the issues in students' thinking (as identified in the FEDORA project) be addressed (and related recommendations implemented) in a futures-learning course? ● How science and societal issues are represented and integrated in students' images of the future? In particular, what is the role of: 1) energy, sustainability and socioscientific literacy in visions of the future, 2) values in images of sustainable futures, 3) relation between "making sense" of energy considerations / physics calculations and "strange making" (uncertainty and "unknown unknowns" of the future). Additionally: 4) how do students connect disciplinary physics knowledge to other disciplines?
OOSN-2023-MUS "Climate Change and the Future of	● Did the scenario-based workshop on climate change promote students' environmental agency? ● Did the scenario-based workshop about climate change affect their

[1] The three FEDORA frameworks are:
- FR1 - 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 (Pucetaite, Rauleckas and Levrini 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 the contemporary challenges (Troncoso, Conti and Tola, 2023)
- FR3 - Framework to Futurize Science Education (Rasa, Laherto et al., 2023)

Learning”	views about teaching?
BOSN-2022-AERO “Aerocene”	● Did students develop sustainability competences through an interdisciplinary art-science project about sustainability? What contribution the course built on contemporary art and, in particular, Saraceno’s vision of a new era free from fossil fuels can give to develop sustainability competencies identified in the GreenComp European Framework? ● Can art support the young to construct images of the future that empower action in the present? ● What tools can be designed to assess whether GreenComp’s expertise has been developed? ● What kind of elements can emerge from this intersection area to characterise the new languages FEDORA project is searching for?
BOSN-2023-AI “Artificial Intelligence (AI) Atelier”	What interdisciplinary context can be designed to make students reflect on topics that the contemporary society of acceleration forces us to think like the potential and critical aspects of artificial intelligence and of the generative machine learning algorithms, the relationship and hybridization of human-machine, and the digital nativity? What are the features and kinds of reflection that can characterise this context? What added value can the interdisciplinarity between art and science have to make students aware of the implications of AI and its latest developments on contemporary society and the future?
BOSN-2023-KAIR “Kairos - To correct the subtle drift of days”	● Which methods did the teachers use for crossing the boundary between literature and physics? What disciplinary concepts have been chosen to connect physics and literature in talking about *time*? ● Which image of knowledge did they want to convey to the students? Which are the implicit values beyond this image of knowledge? ● Did the students show some resistances? If so, what types of? How did the teachers manage them?
BOSN-2023-SIM “Simulations of complex systems”	● Do the students’ perceptions of the future change throughout the module? If so, how? ● Do the students recognize the change in their future perception? If so, how? If not, why?
BOSN-2023-QUAN “The second quantum revolution”	● Do the students develop interdisciplinary skills? What contribution the course on the Second Quantum Revolution and its interdisciplinary nature can give to develop interdisciplinary skills as well as to promote quantum literacy and educate to the quantum future? ● What kind of activities can promote a widening of the “space of meanings” of the main quantum concepts/topics addressed and of the

	more revolutionary aspects? What narratives can be developed to guide students in an inquiry into the epistemic structure of quantum physics? ● Do the students' change their perception of the future? What contribution the course and the epistemic vocabulary of quantum physics in combination with futures studies can give to change students' perception of the future?

Methodologies for the design and analysis of the implementations

As those of the first round, the implementations were built by following a design-based research method (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003). Consistently, the teaching activities and materials have been co-designed and realised within the three OSNs through an iterative process of designing, testing, and revising, according to back-and-forth dynamics between theoretical hypotheses and empirical results. This process informed the way of materials production such that it didn't follow a linear process (preparation, implementation, and evaluation) but a back-and-forth, multiple-round, dynamic process of revision and refinement.

Concerning this second round, the different RQs were addressed by analysing the data through a set of methodologies, mainly qualitative-based - like pre-post comparisons of open questionnaires, interviews, focus groups, and students ' stories - and referring principally to Grounded Theory (Glaser & Strauss, 1967), Thematic Analysis (Braun & Clarke, 2006; 2019) and Case Studies (Yazan, 2015).

Highlights of the results achieved

While the first-round implementations had been analysed in separate studies and already published in papers and/or chapters of theses as well as presented in dissemination contexts, the second-round implementations are still undergoing a process of analysis. For the scope of this deliverable, we summarise in Tables 11-17 a **Brief excerpt of the results** (first column) and the **Highlights on the effectiveness of the materials** (second column) for each implementation.

My city of the future

Brief excerpt of results

The methods included: thematic analysis of final poster-form future visions, with a focus on systemic thinking; Thematic analysis of students' weekly and post-course reflection exercises, with a focus on learning goals, epistemic emotion, thinking skills, futures thinking, images of futures.

From the reflection exercises, preliminary results of the analysis support that students' futures thinking became more positive, where experts' inputs and explicit future-oriented activities were useful. The students deepened their understanding of complex, systemic future-oriented issues.

Students reported learning ways of dealing with and accepting uncertainty, and found ways of perceiving the future with agency instead of hopelessness. Here, the future-making approach was found useful, and the data shows the visiting experts' positive impacts on inspiring and motivating students' visioning processes.

Based on the students' future projects, we found the course supported students in perceiving causal effects of human decisions and actions on nature and the biosphere. The data supports the notion that the students moved from simple and vague images of the future to complexified and more scientifically literate images featuring developed technologies and living environments. This transition happened on one hand in relation to sense-making activities such as lessons around energy production, and on the other hand in relation to strange-making activities such as imaginative distancing. The data also supported the idea that the course challenged students' perceptions of future uncertainties and allowed them to develop coherent, multidimensional visions of the future.

Highlights on the effectiveness of the materials

Students begin to conceptualise the future in a more positive, hopeful manner as compared to experiences before the course. Students gain inspiration from the experts challenging their ideas as well as from the learning activities on framing mindsets towards future changes.

Students show deeper consideration of topics as compared to before and start of the course. They indicate fuller consideration of the complexity of societal and environmental matters, shown through increased systems thinking in terms of the topics considered during the course and their developments during the learning process.

Students learn ways to understand and deal with uncertainty. They explore how to move from certain, hopeless futures with fixed mindsets towards more openness to alternatives and acceptance of the uncertainty of the future, whilst exploring the changes through analysis of agency and drivers of change.

Students consider causal effects of human decisions and actions on nature and the biosphere (e.g. analysing the impact of different forms of energy production on sustainability, and understanding the infrastructural changes needed to create a more environmentally friendly future).

These are researched using thematic analysis of final poster-form future visions, with a focus on systemic thinking; and thematic analysis of students' weekly and post-course reflection exercises, with a focus on learning goals, epistemic emotion, thinking skills, futures thinking, images of futures.

Concerning the results on the diversity responsiveness, the course was implemented with student diversity in mind. This entailed a degree of openness in how (with what approach, on what level) students addressed the future of the city; but also with flexible support based on students' weekly reports.

The diversity responsiveness can be further elaborated using the data collected on students, which includes gender identity, academic background, cultural background, parents' education level, and student's interest in science.

Climate change and the Future of Learning

Brief excerpt of results

The methods included pre- and post-workshop questionnaires, Group discussion recordings, and quantitative analyses on the questionnaire data.

The workshop has significant and positive impacts on students' environmental agency and views about teaching.

- Did the scenario-based workshop on climate change promote students' environmental agency?

  → Analyses of the questionnaire data showed that the scenario-based workshop has positively impacted students' environmental agency. In particular, after the workshop they felt it was more important for them to look after the environment. They felt they were more able to identify some consequences of climate change and more inclined to alter personal actions to combat climate change.

- Did the scenario-based workshop about climate change affect their views about teaching?

  →This variable was measured by three items in the questionnaire and only one of them resulted in significant differences between students' pre- and post-workshop perception. The climate change workshops increased students' motivation for teachers linking topics in science to other subjects (interdisciplinary learning).

Highlights on the effectiveness of the materials

Students were very interested in the input of the workshop. The materials used include videos, data charts, many artworks, and museum exhibits. Their reactions and the feedback given after the workshop indicated that their interests in the issues have increased, especially in linking science learning to other subjects (interdisciplinarity), emotions (imagination skills), and their agency of taking actions to help climate change (future-oriented thinking and responsible engagement with the future). These can be found in the feedback provided in their post-workshop questionnaires. Effectiveness of the materials is evident in the positive impacts of the workshops on students' environmental agency and their perceived future literacy (see the section above). Effectiveness is also assured based on students' active participation in the workshops and excellent feedback afterwards - they had very lively group discussions and gave very interesting and creative presentations. The teacher participants were also interested in the workshop materials and requested a copy from the Oxford research team. The science teachers wanted to use the workshop materials as basis for their subsequent revision of the scheme of work in school and setting up of a new school club connecting science to art. A resource pack for the classroom is also produced (in electronic and hard copies) for wider dissemination. The pack focuses significantly on gender issues and careers and contains four sets of materials adapted from the first round of implementation.

“*Aerocene*”

Brief excerpt of results

The methods included analysis of a questionnaire, and thematic analysis of the final essays.

The first result concerns the design of a questionnaire to assess the development of the competences outlined in the Greencomp (Bianchi et al., 2022) through an interdisciplinary art-science project about sustainability.

	1. Embodying sustainability values			2. Embracing complexity in sustainability			3. Envisioning sustainable futures			4. Acting for sustainability		
	1.1 Valuing sustainability	1.2 Supporting fairness	1.3 Promoting nature	2.1 Systems thinking	2.2 Critical thinking	2.3 Problem framing	3.1 Futures literacy	3.2 Adaptability	3.3 Exploratory thinking	4.1 Political agency	4.2 Collective action	4.3 Individual initiative
Q4							X					
Q5							X					
Q6			X									
Q7							X					
Q8												
Q9	X				X	X		X	X			
Q10	X				X	X		X	X			
Q11							X					
Q12									X			
Q13			X					X	X	X	X	
Q14									X			
Q15									X			
Q16							X		X			
Q17												
Q18	X						X		X		X	X
Q19												
Q20								X	X	X	X	
Q21												
Q22												
Q23												
Q24									X			

Fig. 7. Relationship between the questionnaire’s questions and the Greencomp competences

In particular, the course, based on Saraceno’s artworks, aims to develop different competences in the four areas of the Greencomp. The competences were carried out by a deep analysis of Saraceno’s Aerocene artwork and the meanings it embodies and by designing an interdisciplinary experience to unpack it in terms of the physics behind the tetro’s flight, the artistic perspective and aesthetic, the future dimension as a space to imagine possible new solutions to the problem of climate change, the values and the rituals behind the tetro flight that belongs to the Aerocene community that embrace artist’s value and collaborate to support climate activism promoting environmental awareness and atmospheric-sensing experiments.

The questionnaire consists of both closed and open questions, aimed to investigate how the work of Saraceno and the course impact and change students’ perceptions of flight in terms of

- moving through the air by solar energy alone, without the use of fossil fuels, batteries, or other devices,
- relationship between humans, non-humans, and environment
- futures, Aerocene as a new possible era and how Saraceno’s vision can inspire the design of a more sustainable future
- personal experience and being part of the Aerocene community (building a tetro’s prototype and make the one provided by the Aerocene community fly)
- new positive attitudes to tackle a difficult issue like climate change
- the added value of the artist’s vision and work.

The questions are elaborated both to investigate what aspects changed but also to activate meta-reflections of the change itself.

From a preliminary analysis of the questionnaire, the tool proved to be effective to assess some of the Greencomp competences and the course proved to be effective to develop these competences.

As regards the first area, embodying sustainability values (in particular, the competences 1.1 and 1.3), by triangulating the closed questions and the open ones, we noted that Aerocene showed students a way of moving through the air in accordance with natural elements and only when weather conditions make it possible. Aerosolar sculptures made learners realise people can create new values and can choose which values to prioritise in their lives. The sculpture, as some students discussed, has fostered students to align their idea of flight with more sustainable values. Furthermore, aerocene makes students aware of their being part of nature and respecting the rhythms of the planet as well as the presence of other life forms.

As regards the second area, embracing complexity in sustainability (in particular, the competences 2.2 and 2.3), in explaining how the idea of flight has changed since the Aerocene experience, students were able to assess information and arguments and discriminate utopian aspects that the project embodies from reality. Some answers show students' reflections on the potential challenges of a sustainability problem, confirming that Saraceno's vision opens the imagination to something real that would be useful in coping with the problem of climate change.

As regards the third area, Envisioning sustainable futures (all three competences), it is the most investigated since it is part of the course's design: the Aerocene art project was created to envision an alternative future by imagining different scenarios and showing the steps needed to achieve a desirable sustainable future. By triangulating the closed and open questions, it emerged that students before the course did not think it was possible to fly without using fossil fuels or energy-consuming devices. The Aerocene project widened students' imaginary and opened the possibility of thinking about objects that fly by means of solar energy and without the use of photovoltaic panels. It showed a new possible future development of flight, maintaining the values and sustainability goals.

Aerocene showed a way to adapt to new situations that require path correction. The experimental aspect of the project allowed students to deal with the uncertainty of the final result, accepting the challenge of experimentation in stages and successive attempts.

The interdisciplinarity between art and science proved to be a "generator" of new ideas paving the way to explore new possibilities and new possible futures. Some students' answers also discussed the role of art, arguing how its language brought a different perspective to the discussion of climate change, generating unexpected ideas.

As regards the fourth area, Acting for sustainability, both close-ended and open-ended questions show that students recognize the need of taking action for sustainability both at the individual and collective level, while the political level was not strongly considered.

At the end of the experience, students were asked to write a final essay to share also with the aerocene community. We are analysing these essays to investigate the potential of the unbound framework for new languages outlined in WP2 for investigating the impact and the potential of Saraceno's languages on students' narratives.

Highlights on the effectiveness of the materials

As discussed, the preliminary results show that the course was effective for the development of Greencomp competences assessed through a questionnaire.

Dealing with the “utopian” work of Saraceno made students develop critical and creative thinking and imagination skills, opening their minds to reflect on new possible solutions to environmental issues.

The hands-on activity of building a prototype sculpture and the flight of the one provided by the aerocene community made students also develop problem-solving skills. Dealing with the interdisciplinary art-science experience on sustainability made students develop agency skills, awareness, and responsible and proactive engagement with science.

As the questionnaire shows, the introduction of climate change, sustainability, and interdependencies between living and non-living beings as complex issues as well as dealing with air variables to make the sculpture flight made students embrace complexity and uncertainty.

For what concerns responsiveness’s diversity, this course was implemented within the Baracca Institute of Forlì. We have only collected gender data. No differences were observed between males and females in their capacity to envision new future’s possibilities and solutions or to change their perception of flight.

Artificial Intelligence (AI) Atelier

Brief excerpt of results

The AI atelier was born from the shared need of a group of teachers to make students aware of the digital environment in which they are immersed since their birth and which they tend to perceive as 'natural'. The activity was therefore designed as an art-science laboratory by an Italian teacher and artist, three teachers of mathematics and physics, and a teacher of philosophy. *Co-design* and *co-teaching* are therefore the two methodologies implemented for the realisation of the AI Atelier. Each teacher had a different role both in the design phase and in the implementation phase of the course in accordance with their competences and knowledge: the Italian teacher took care of the artistic aspects and comparison between human and artificial creativity by searching, discussing, and analysing examples drawn mainly from the history of art that deals with the theme (AI and art), the professor of philosophy dealt with a reflection on the comparison between human and machine intelligence, the professors of mathematics and physics took care of the technical and formal aspects of the AI, introducing topics such as the difference between symbolic and connectionist approaches, machine learning, the current generative algorithms underlying artificial intelligence such as chatGPT and other ideas to reflect on "smart machines" and how they think. From the analysis of the documents that the teachers together with the students have created and published on the school website and from the qualitative analysis of the final interviews with the teachers, it is emerging that this comparison between artistic thinking and human creativity and creativity of artificial intelligence became the scaffolding to reflect on the role of artificial intelligence today, on its potential and its limits. The art-science interdisciplinarity, intertwining with the philosophical, epistemological, and ethical dimensions has therefore become a context to develop critical thinking and involve students in a reflection on the relationship between humans and machines and possible sustainable hybridization. Going into detail, this designed comparison between the different creativities, intertwined with the philosophical perspective, in the examples presented allows teachers to touch on some key considerations to encourage a critical reflection on the phenomenon of AI and art. First, at the basis of the creative processes of AI, structured on deep learning, there is a combination of information, data, and labels found in the network. The proposed examples thus highlight how historically artistic works have been constructed based on the combination of images and concepts. In particular, it was reflected how this *ars combinatoria* was characterised, even when played on the irruption of the case as in certain avant-garde practices, by the relationship between the artist and his *historical-cultural context*. The first consideration, therefore, concerns the discriminating factor of the context that the artist has always had present, even when he intended to deny it or critically take the distance to address an unreal or surreal dimension. These processes do not coincide with the creativity of man because of the lack of awareness of the relationship with his own time and the peculiar psychological experience that structures human consciousness.

The relationship with the context has led to a second consideration that concerns the concept of the *limit* that every human experience lives necessarily because of the mind and body at the same time. Also in this case, human experience cannot be reproduced in the digital dimension, which for example cannot be measured by the limits imposed by matter in relation to which each artist generates his own work as is more traditionally understood: the concepts to which the artist is called to give a shaper, even if abstract and symbolic, are the result of an experience that only the artist can conceive since, as a human, he/she is called to measure and generate his/her thoughts on the horizon of a limit. The limit of artificial intelligence is the amount of information, data, text, and images on the internet. This great quantity generates the illusion that such systems of intelligence can record all reality and, therefore, their reworking could be understood as the actual ability of the machine to be able to say and represent all the real, giving artificial intelligence an oracle status. Generative algorithms like ChatGPT are not able to get out of the digital reality and the information on the internet does not coincide with all the reality that we live, that we perceive through our senses and that record selecting it according to our wishes, shortcomings, etc. and thanks to human thought.

The AI atelier and the teachers who created it, therefore, an interdisciplinary context between art, science, and philosophy that has become a laboratory of thought in which students, between the proposed examples and their final work, led them to realize artworks with the use of current generative algorithms (chatGPT, DALLE, and Midjourney), not only have tested and reasoned on how these algorithms are creative and can, together with the artist, generate new aesthetics and languages, but they have also reasoned on the digital environment in which they live by touching "with hand" what is artificial intelligence today and how you can live sustainably with it.

Highlights on the effectiveness of the materials

The initial analysis of the teachers' interviews and of the documents published on the school's website shows the value of interdisciplinarity from different perspectives. First, interdisciplinarity between art, science, and philosophy in terms of *co-design and co-teaching methodologies* proved to be effective to *create a space* to touch on pivotal aspects and debates concerning the AI and its relationships with humans that are characterising contemporary society.

The interdisciplinarity between art and science, in terms of the comparison between artistic thinking and human creativity on one hand and "artificial creativity" on the other, promotes the development of *disciplinary* and *interdisciplinary skills* supporting students to recognize and question the peculiarities and differences between the two kinds of creativities as well as the value of their combination. This is evident mainly in the artworks' descriptions in which students describe the theme and the kinds of reasoning they elaborated and conceptualise in their artworks and how they integrated the different intelligence and created their artworks through the interaction with an artificial intelligence like ChatGPT, midjourney, and DALL E. Furthermore, students' engagement in the realisation of an artwork, of a new aesthetic through the interaction with the AI as well as their involvement in a creative process promoted the development of *imaginative* and *creative thinking*.

The interdisciplinarity in terms of intertwining between art, science, and philosophy promotes, as discussed, the development of *critical thinking* and *awareness* about contemporary debates about science and technology, the relationship between humans and machines, and the potential and dangers linked to the digital world in which we are immersed. The final artworks of the students and their descriptions suggest their effectiveness because they are realised starting from aspects related to art and AI that particularly impressed them.

Finally, the interdisciplinary space has the potential not only to make the students aware of the debates concerning AI of contemporary society but also to provide skills to design new narratives and languages to better grapple with the present and to imagine more ethical and sustainable relationships between machines and humans.

Kairos - To correct the subtle drift of days

Brief excerpt of results

The methods include Ethnography and Qualitative analysis of recordings.

The physics teacher systematically repeats crucial words of complexity and elaborates different narratives around the concepts of complexity. The role of words as boundary objects is the idiosyncratic teaching style of the teacher and the way she connects physics with literature. Another interesting feature of the activity are the moments of co-teaching, where the two teachers were interchanging; so for example sometimes the Physics teacher monitored alone the writing process of students in class, while other times the literature teacher made some comments and rephrased the words of the colleague, within a Physics lecture. In this sense, seeing this interconnection between the professors, fostered for students the idea that disciplines and teachers can *talk together*, can *exchange ideas*, *thoughts and perspectives* upon a topic, such as time.

For what concerns the disciplinary concepts used, the choice to use the Greek interpretation of time, and map the features of complexity addressed in the lectures into the four types of time, allowed teachers to shift from physics to literature in a way that made sense for students. In particular, each kind of time was read with the concepts of complexity, but was also interpreted with the double lens of comic and humoristic, coming from the work of Pirandello. On one side, the scientific content was providing features to the essays (circularity of time, time that emerges), whereas on the other side the humoristic/comic dualism was providing a way to express those features, without explicitly describing them in words.

The teachers wanted to deliver the message of the value of these epistemic practices as general lenses, which can be used to make sense of the complexity around us.

Non the less, students reported difficulties:

- In grasping the concepts of self-organisation, emergent behaviour, and deterministic chaos. What is more difficult for them is to recognise these concepts as phenomena occurring in their daily lives.
- To deal with this difficulty, the physics teacher: i) presented different examples of complex systems known to the students (through videos, through simulations) besides two experiments, which could increase the span of the theoretical concepts faced; ii) asked them to take pictures of things (around the city) that in their opinion could be considered as complex systems.
- In understanding the sense and the value of connecting the physics of complex systems with theatre, to see the two parts of the module as reciprocally important.

Highlights on the effectiveness of the materials

For the state of the analysis, we are just able to check the presence of these skills referring to what we saw so far in class. Students are increasing their imaginative skills in the sense they are struggling with writing stories, where they have to report the four Greek interpretations of time (see above), within the characters and the scenes’ structure. They are at the same time improving their interdisciplinary skills while working on the mapping between concepts of physics and writing techniques. Though, this process seems not easy, and requires constant interaction with the teachers, especially with the literature.

We plan to measure the evolution of such skills by taking traces of students' thoughts and impressions in an activity-diary, of which they are in charge; in this case see if some shift is reported, regarding their ability and confidence in crossing the boundaries between the two disciplines.

The evaluation of the final pieces, as well as the evaluation of the intermediate versions will allow us to see to what extent students were able to deal with the boundary-crossing, and also to what extent they seem to have developed strange-making skills.

The sample was perfectly homogeneous, since we had 12 males and 12 females participating in the activity. The fact that each student within the group was in charge for a specific scene, allows us to analyse the artefacts considering gender as a variable.

Simulations of complex systems

Brief excerpt of results

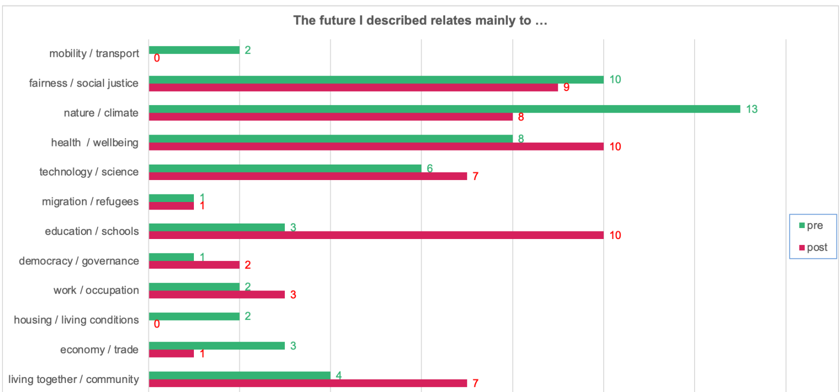
Several data were collected during the implementation. In particular, to answer the RQs, the following data sources are considered:

- Students' answers to the Sensemaker questionnaire before the beginning of the implementation
- Students' answers to an open-ended questionnaire on the change of their future's perception with respect to the narrative they had written at the beginning of the course - the questionnaire was filled in by the students before the last meeting
- Students' answers to the Sensemaker questionnaire at the end of the implementation

To analyse the data, a qualitative analysis was performed to compare the pre and post entries in the Sensemaker questionnaire (RQ1) and to check this comparison against the students' narrative of their perceived change throughout the module (RQ2).

Even if the analysis does not aim at being quantitative, between the pre- and post-questionnaire we observe a significant deviation from the distributions:

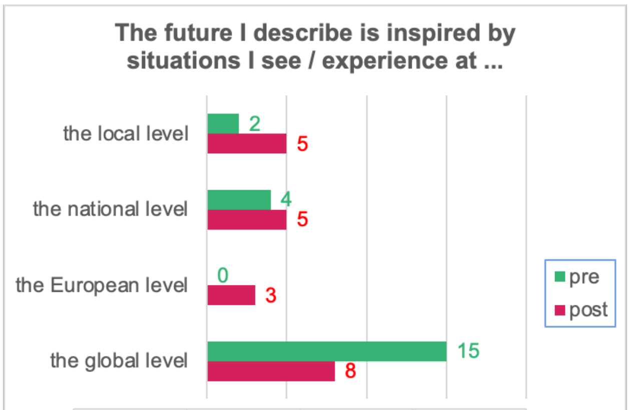
The narratives of the students show a remarkable increase in the category of education and school, probably due to the task of the future-oriented activity that required to imagine the school of the future; another category that increased a lot in the post questionnaires is that related to living together and community. On the opposite, the narratives of the students at the end of the course are less related to nature and climate.



	living together / community	economy / trade	housing / living conditions	work / occupation	democracy / governance	education / schools	migration / refugees	technology / science	health / wellbeing	nature / climate	fairness / social justice	mobility / transport
pre	4	3	2	2	1	3	1	6	8	13	10	2
post	7	1	0	3	2	10	1	7	10	8	9	0

Figure 8. Comparison between the pre (green) and post (magenta) answers to the SenseMaker questionnaire with respect to the topics self-identified by the students in their narratives.

In the post-questionnaires, the narratives of the students shift the focus from the global level to the local, national and European ones. We hypothesise that this is due, on the one hand, to the use of computational simulations (which allow to focus on the individual components of a system and on their local components), and on the other to the choice of analysing the school as a problem closer to students' lives and experience in the future-oriented activity.



	the global level	the European level	the national level	the local level
pre	15	0	4	2
post	8	3	5	5

Figure 9. Comparison between the pre (green) and post (magenta) answers to the SenseMaker questionnaire with respect to the spatial scale touched by the narratives.

In the post-questionnaires, we observe a more plural view of the agents of change. Instead of 5, only 1 narrative in the post-questionnaire remains anchored to an actor of change only: the others combine more than one expertise to produce significant transformation.

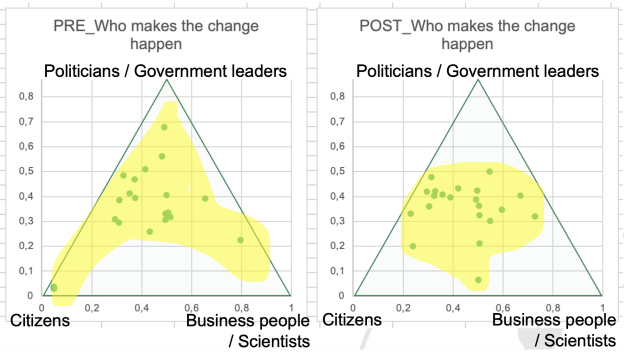


Figure 10. Comparison between the pre (left) and post (right) answers to the SenseMaker questionnaire with respect to the actors of change in the system (citizens, politicians or government leaders, business people or scientists).

The pre-post analysis articulated across the two groups of students who perceived or not a change in their future perception, did not reveal significant differences among the two groups. The answers to the Sensemaker questionnaire change between pre and post for both groups in similar ways, for all questionnaire items. This reveals students' difficulty in recognizing the change in future's perception that took place throughout the course.

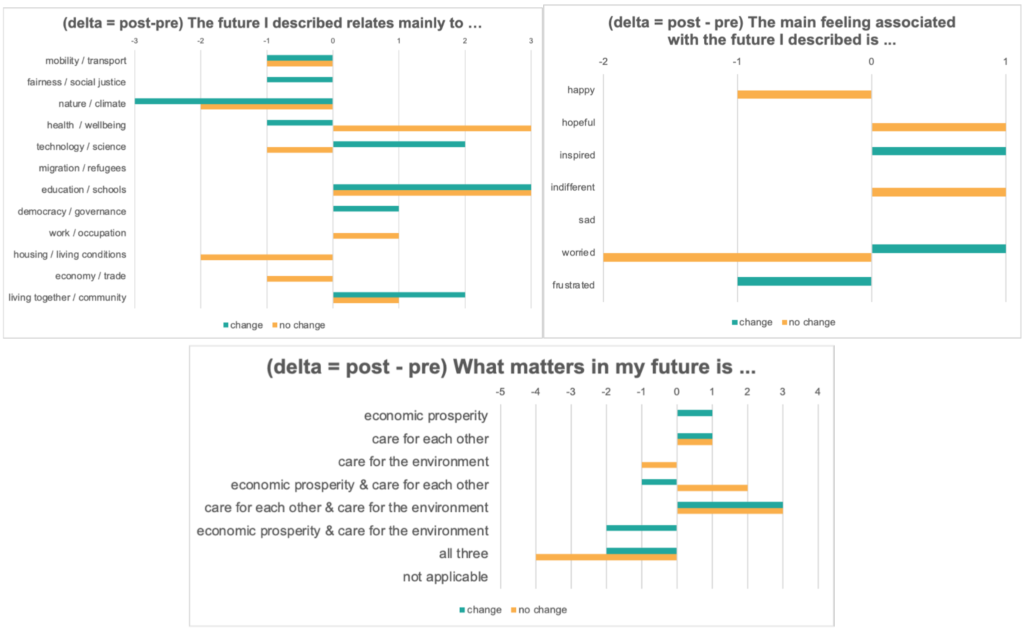


Figure 11. Comparison between the groups of students who said to have changed (turquoise) or not (yellow) their image of the future. The comparison is measured in terms of the difference (delta) between the number of pre and post answers for each category. The comparison is exemplified for three different types of questions: the topics related to the narratives (left), the main feeling associated with the narrative (centerand), and the most important thing in the future according to the narrative (right).

Highlights on the effectiveness of the materials

At the end of the module and of the future-oriented activities, students changed their vision of the future and the description of the future's narrative. Even if they are not always able to recognize the change that occurred, they stated that the course helped them to widen their imagination toward the future in terms of new possibilities and in the modalities of scenarios' construction ("My idea of the future hasn't changed, but the course helped me think of new possibilities to improve the problem. Acting at the root starting from education, in particular from new types of education such as those we have seen during the course can be very useful, and also thinking of arriving at the solution by retracing the various steps instead of proceeding from the present to the imagined future can help in developing better solutions" F23).

To measure the change in the future's perception, we used the Sensemaker questionnaire (submitted before and after the course) and a self-reflection questionnaire in order to check the awareness of the change.

With regard to the diversity responsiveness, in the selection of the students, we monitored their gender, and the work in groups was organised accordingly. A pre-post analysis was conducted to monitor the presence of gender differences in the perception of the future. Before the course, the themes covered by the narratives were more different between males and females (females more focused on fairness and social justice, education and housing; males more focused on mobility, nature and technology) than those reported at the end of the course that appear more uniform. No significant differences were observed in the module's impact on future's perception.

Also, for what concerns the perception of change, no significant differences were observed, with a comparable number of females and males recognizing or not the change.

We also collected information on the socio-economic background as well as some demographics that were built-in in the Sensemaker questionnaire.

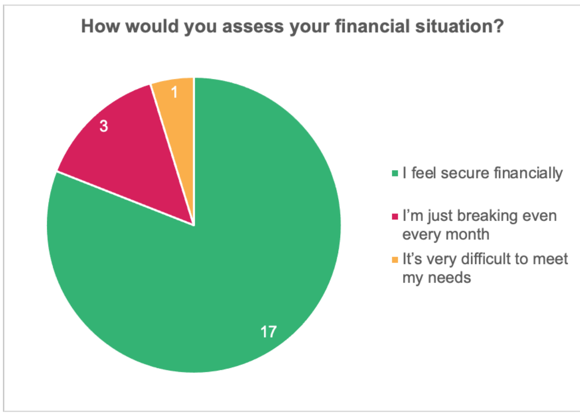


Figure 12. Example of the demographic question about the students' self-assessment of their financial situation.

Moreover, in the design of the activities, a central role was devoted to the societal impact of simulations, an aspect that the literature shows that it contributes to the diverse responsiveness of educational materials.

The second quantum revolution

Brief excerpt of results

The methodology included the analysis of the pre- and post-answers to the sense maker questionnaire, thematic analysis of students' future narratives, qualitative analysis of collective discussions, and of final collective interviews.

As regards the interdisciplinary theme, the initial qualitative analysis shows that the construction of a 'shared space' of authentic dialogue between disciplines and of conceptual tools linked to the epistemological structure of

Quantum physics promoted the development of different skills. During the implementation, different disciplines (in particular physics, mathematics, and computer science) were compared, intertwined, and integrated fostering students to recognize different perspectives (e.g. disciplinary identities) and make connections between them (interdisciplinary skills). In particular, these aspects were monitored during the lessons by asking students to find connections and discuss representations belonging to different disciplinary domains (i.e., the circuital representation and the experimental representations of the teleportation protocol). Furthermore, we administered a questionnaire and conducted final collective interviews to investigate how the different representations and languages that belong to different disciplinary domains help them to understand quantum technologies. We are analysing the questionnaires and the interviews. In general, students proved to be able to recognize disciplinary aspects and make connections. They found effective the explicit focus on different languages and representations and verbalised the impact of the link between different representations and languages belonging to different disciplinary domains on how they can make sense of the content. This can lead to establishing a dialogue between different disciplinary territories and to activating a process of translation from specific linguistic systems into others, giving the opportunity to enhance the communicability of STEM disciplines themselves.

As regards the theme of the future, from the analysis of the activity of the classical and quantum demon, the narrative rational structure of the demon proved to be effective to recognize the epistemic structure of quantum physics and to identify the key themes that promote students the shift of paradigm to implement in the activity of scenario building. The demon narrative proved to be effective in making students reflect on the main differences between the two paradigms focusing on the dimension of time, the kinds of knowledge that the demon embeds, the space of uncertainty, and the kinds of relationships between different events.

The scenario-building activity was designed to reduce the polarisation effect we observed in the previous analysis in which students closed themselves into their rituals, or imagined themselves separate from the rest of the world. The activity, in fact, was designed to make them reflect at the level of the city and to balance different dimensions (such as political, societal, economical, ethical…) and the needs of different possible stakeholders.

As regards the students' future narratives, we analysed the answers to the sense-making questionnaire administered before the beginning of the course and after as well as the students' future narratives through a thematic analysis. From the comparative analysis of the answers to the sense maker questionnaire (pre- and post-), the main aspects we noticed are

- *A shift from a general or European level to a local or national one*. This trend is first detected in the questionnaire. From it, we observed a transition from narratives mainly inspired by global situations to narratives inspired by local or national situations.

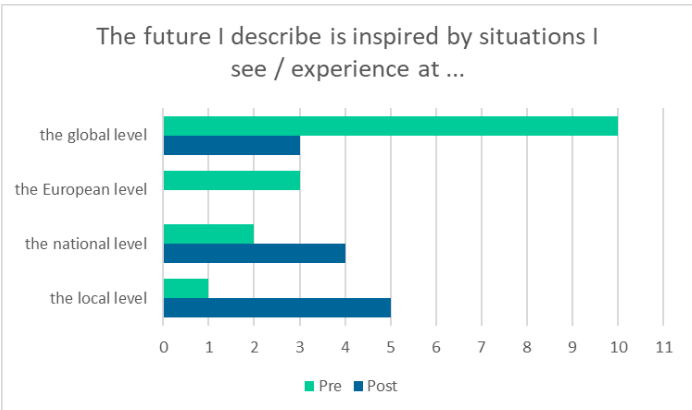


Fig. 13: Comparison between the pre (green) and post (blue) answers to the SenseMaker questionnaire with respect to the spatial scale touched by the narratives

This was then intertwined with the thematic analysis of students' future narratives. The initial narratives of the students touch on very general and generic themes such as environmental issues, pollution, inequalities, wars, hunger, and society as a set of individuals who cooperate to solve a problem. Except for 2 out of 15 narratives where students touch on issues explicitly related to the Italian situation (the lack of sense of what they study in school and the need to rethink the school and the problem of brain drain), the other narratives do not enter into the merit of the problems. The final narratives were produced in groups and derived from a scenario-building exercise. Students were asked to describe the desirable city they would like to live in according to a set of constraints we gave such as the city has to embody a societal, economic, political, and environmental perspective, it should reflect a set of values that regulate the relationship between humans, technology, and nature. The process of scenario building and the constraints made students reflect on the level of the city and to focus on the issues they would like to be fixed in 2040 at the local ecosystem (i.e., public transport, changing the attitude of the conservative policy-makers like the mayor toward technology, the integration of technology in many economic sectors, city's water reclamation, the birth of educational centres that dialogue and collaborate with Europe, a welfare improvement of the citizen starting from education, etc.).

- *The centrality of education and schools and science and technology dimensions.* The analysis of the pre- and post-answers to the sense maker questionnaire shows that in the pre- the dimension of school and education was almost absent (1 out of 15). Even if we did not ask explicitly to discuss this dimension, it became central in the post-questionnaire.

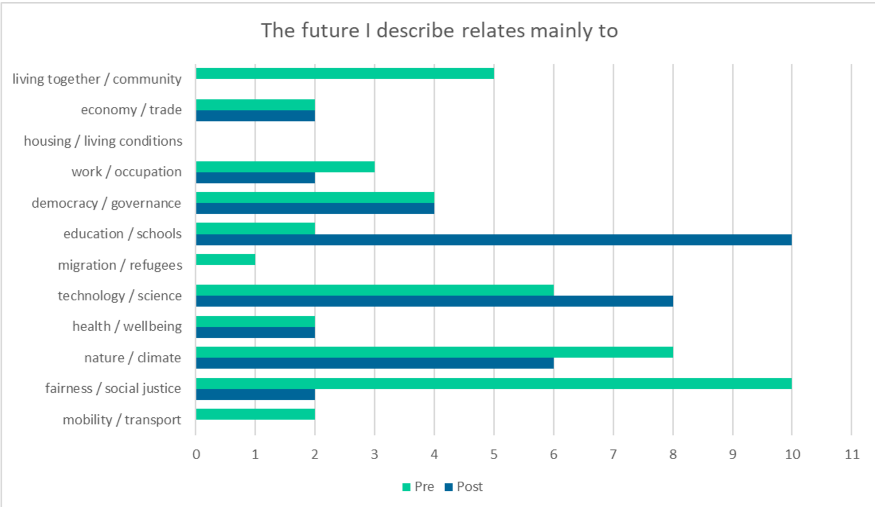


Fig. 14: Comparison between the pre (green) and post (blue) answers to the SenseMaker questionnaire with respect to the topics self-identified by the students in their narratives.

From the analysis of the final students' narratives, all the students express the desire to have a more accessible, more egalitarian school (with investments to guarantee everyone the right to study) and a better selection of teachers, and a better welfare of the teaching condition.

It is the case also of the science and technology dimension. It is a dimension present in some answers (5 out of 15) of the pre-questionnaires as, as the analysis of the narratives shows, an abstract entity (students wrote generally technology, technological progress,...). In the post-questionnaire, it becomes fundamental. Students explicitly refer to research centres in the city, and discuss the role of technology at the local level (i.e. how technology can help various sectors such as fishing and mechanical ones, and transports).

Other observed trends that the scenario-building activity seemed to have triggered are:

- the shift from a change mainly promoted by citizens/groups of citizens and business people/scientists to an idea of change promoted more by Politicians/Government leaders and business people/scientists. Looking at the narratives, even if we asked students to reflect also on the individual dimension, the narration is quite impersonal, and they did not reflect on themselves as an integrated part of the city. The only reference to the dimension of the citizen is linked to the improvement of personal welfare, but it is not clear how students framed themselves within the city. The activity will be refined to add this layer.
- A more balancing among the vertex of "what matters in your narrative". While in the pre-questionnaire students assume more spread and polarised positions, the narrative of the scenario-building activity seems to make students reflect on the necessity of reaching a balance between economic prosperity, care for each other, and care for the environment.

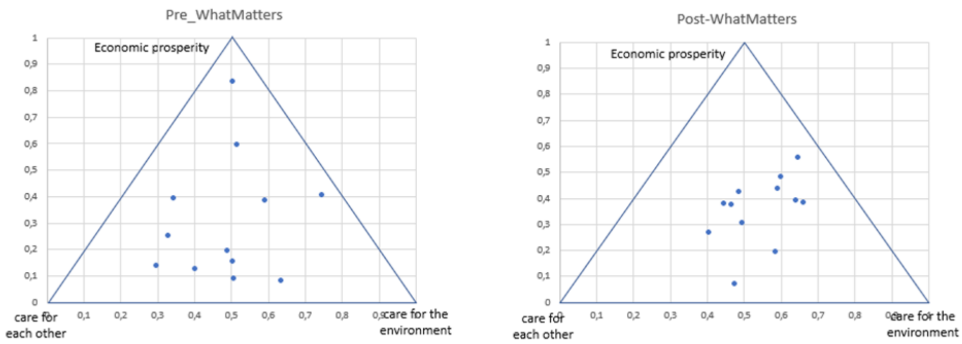


Fig 15: Comparison between pre and post-answers to the SenseMaker questionnaire with respect to what matters in personal future.

- An improvement of the attitude in terms of probability to realise one's own future. The pre and post-tests show a shift to a more likely vision of students' personal future.

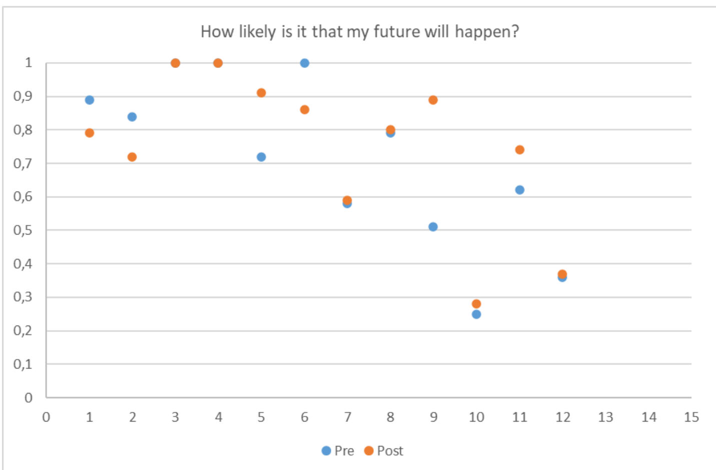


Fig. 16: Comparison between pre and post-answers to the SenseMaker questionnaire with respect to students' attitudes toward their future

In general, the future-oriented and citizenship education activities like the scenario-building activity and the analysis of Eve's city, prove to promote the development of a more conscious and critical vision of the future, and responsible and proactive engagement with science and society. Furthermore, the constraints of the scenario-building activity and the idea of "design the city you would like to live" seemed to help students to think more critically, to take into consideration a plurality of dimensions and stakeholders "entangled" with each other, balancing the need of the single individuals (mainly in terms of well-being) and a more global perspective.

Highlights on the effectiveness of the materials

The initial qualitative analysis shows that the construction of a 'shared space' of authentic dialogue between disciplines and of conceptual tools linked to the epistemological structure of quantum physics promoted the development of different skills. During the implementation, different disciplines (in particular physics, mathematics, and computer science) were compared, intertwined, and Integrated fostering students to recognize different perspectives (e.g. disciplinary identities, disciplinary skills) and make connections between them (interdisciplinary skills).

The future-oriented and citizenship education activities promoted the development of critical thinking and responsible and proactive engagement with science and society and agency.

Furthermore, the activities developed, designed to futurize science education, proved also to promote probabilistic thinking, risk acceptance, embrace ambiguity and manage the equilibrium between sense-making and strange-making skills.

For what concerns diversity responsiveness, in students' selection, we monitored their gender, and the work in groups was organised accordingly. Through the Sense Maker questionnaire, we also collected information on the socio-economic background as well as some demographics. The sample was very homogeneous so for this specific trial, we did not think we should take this variable into account. However, we believe that these are not negligible data that have been stored in accordance with the legislative regulations and will be used later to reason on the different trials.

Moreover, a pre-post analysis aimed to monitor the presence of gender differences in the perception of the future. The only aspect we noted concerned the pre-test answers. From the thematic analysis, we saw that there are some common themes that most of the narrative touches such as the climate issue, respect for the ecosystem, the importance of, as individuals, the collaboration, and equal rights.

Many other themes are different between males and females: females mainly focus on social justice, social differences, and diversity, equality, and equal opportunities; males are more focused on better salary, free time, research, and finding new kinds of energy and technology. No significant differences were observed in the course's impact on future's perception.

Relation of the implementations with FEDORA frameworks

As was said in the introduction of this document, the second-round of implementations was strongly shaped both by the results coming from the first-round of implementations and by the three FEDORA frameworks on interdisciplinarity (FR1), new languages (FR2), and future (FR3). These three frameworks pointed out the main issues in the areas and elaborated specific recommendations intended to address the issues. Operatively, the recommendations were used as principles which guided the design and the refinement of the second-round.

In order to keep a tension between the global structure and results at a level of the project and the specificities at a level of the local contexts, each implementation have identified how related to the three frameworks. As a note, we would specify once again that like it was not mandatory to simultaneously cover the three main pillars of the project or to simultaneously achieve the learning outcomes on the three main areas, it was still not compulsory to simultaneously implement the recommendations coming to FR1-2-3 or to give to them the same level of relevance. Indeed, despite at the very end almost all the implementations covered almost all the three, some implementations were particularly devoted to better explore some issue.

In this section, we present, implementations per implementations how they related to FR1-2-3.

My city of the future

The design and delivery of the Helsinki implementation have addressed all the three FEDORA frameworks.

FR1: The approach used in the UH implementation, namely the context of the city for a futures learning course, seems to have supported students in improving their structural thinking. The city as a familiar but complex topic seems to have provided a anchoring point that “builds on existing knowledge and draws structural interconnections” (FR1, p. 14) while also supporting “systems thinking, boundary crossing, socio-cultural awareness, and integrative research” (p. 5) as well as “civic participation” and “recognition of the ethical dimensions of decision-making in differing social contexts“ (p. 15). The course provides an example of formal teaching that deals with FR1 issues such as “Practising interdisciplinarity” (by providing a supporting structure) and “lack of interdisciplinary language” (by supporting the discussion with context, representation of knowledge areas, and explicitly allowing uncertain future-oriented argumentation).

FR2: The My City of the Future course was built strongly on the principles of “triggering epistemic emotions” and “going beyond dichotomous thinking”. By imagining and discussing Helsinki in 2050, we invited students to a space of indeterminacy: the course was primarily a place of discourse, and the learning activities were set to support the discourse rather than direct it to a fixed endpoint. We engaged students in storytelling, moving from speculative design to scenario work and back (see FR2 p. 23, p. 26).

FR3: As a future-oriented science learning course, the UH implementation was also built on FR3 and its recommendations. We used future thinking to cross between the political and scientific (recommendation IV); we supported students futures’ thinking by learning basic concepts from futures studies (recommendation V). We elicited students’ explicit and implicit images of the future, scientific and technological change, and human agency in creating the future (recommendations VI-VII). We also embraced uncertainty, and complexity and collectively crossed from individual “bubbles” to collective future-making (recommendations IX, XIII, XIV).

Climate change and the Future of Learning

The design and delivery of museum workshops on climate change in Oxford have addressed all the three FEDORA frameworks.

FR1 (Addressing interdisciplinarity): The first part of the climate change workshops regarded climate change not only a scientific challenge but also a socio-political and personal problem. Examples were discussed with students how solving this global problem requires a wide range of expertise such as scientists, science communicators, artists, teachers, journalists, politicians and students/young people. This segment illustrated "the interconnections of jobs and professional roles to address collective challenges" (p.9) in the framework. Students suggested in the questionnaire what other school subjects are related to the topic. Their responses demonstrated a "recognition of the roles of disciplines that are studied in school curricular to tackle interdisciplinarity" (p.9). The massive use of art pieces and the discussion of how artists help combat climate change has widened "STEM to STEAM to include arts and humanities" (p.9). The art element has profoundly contributed to "the inclusion of arts as languages that can facilitate the inhabitation of the boundaries between disciplines (p.9).

FR2 (Diving into new languages): Using plenty of artwork and ancient paintings in the workshops have eminently emphasised "arts as languages to understand and discuss global issues" (p.9). The ample art addition to the second-round implementations provided students a sharp contrast so that they could evaluate what they usually read in other traditional communications about climate change. In this way, a "third space in between science and arts" was created through the workshop activities and the selected art materials. Students were shown how to "combine, mix and acknowledge non-traditional ways of communicating" for their scientific ideas (p.9).

FR3 (Dealing with the relationship between present and future): The workshops adopted a scenario-based teaching approach which guided students to imagine multiple possible futures, both positive and negative, thus presenting to them "the plurality of futures" (p.11). The selected video materials and climate data successfully persuaded students about the urgency of this global problem, which in one way or another, elicited their "fears and desires about personal and collective future scenarios" (p.9). Students also discussed various examples of environmental actions, measures or policies at personal, school, local and national levels, and their own role situated at those levels. This segment exemplified "the choice of contexts to students' life and experience for which elaborating future scenarios, in a way that they can find their own space of agency" (p.10).

Aerocene

The design and delivery of the Aerocene activity had the ambition to mainly address and elaborate on ***FR2*** framework.

Indeed, the experience strongly referred to the two main general objectives of WP2: (i) To analyse new languages and forms of knowledge transmission that will be useful to enhance imagination and the capacity to talk about the contemporary challenges, to equip teachers, teacher trainers, and their students with linguistic, argumentative, and imaginative thinking skills needed to face current challenges; (ii) To experiment with innovative communication approaches to future science education, giving the youth a chance to perceive, imagine and ultimately envisage and thus shape the future.

In particular, Aerocene was thought from the beginning as an interdisciplinary activity, at the boundary between arts and science involving an art piece by the argentinian artist Tomàs Saraceno. The artwork, part of a project called by the artist "Aerocene" (https://aerocene.org/), consisted in an aerosolar sculpture that helped people to imagine new and more sustainable ways to fly, "reactivating a common imaginary towards an ethical collaboration with the environment and the atmosphere, free from carbon emissions".

The Aerocene implementation contributes to detect, sample and analyse examples of contamination and cross the intersection of narratives about science and on science, which use different epistemic approaches as well as a variety of languages. Saraceno's artworks were unpacked to recognise the cultural potential in terms of physical, artistic, and societal meanings as well as in terms of envisioning new possible futures and solutions to environmental issues.

In its development this work also tried to touch the four kinds of new languages pointed out by the framework: 1. Languages for adaptation: they relate to evolution; 2. Languages for foraging futures: they relate to time; 3. Languages for uncharted territories: they relate to space; 4. Languages for interdependencies: they relate to interactions. The realisation of Saraceno's artworks with the students and the discussion about this ambiguous and boundary object concretises them in examples through students' narratives.

Artificial Intelligence (AI) Atelier

The design and delivery of the AI atelier in Italy have addressed mainly two out of three FEDORA frameworks.

FR1: the AI atelier is an example of a sustainable trading zone in which teachers, implementing co-designed and co-teaching methodologies, created choreography to safely guide participants to "embrace the ambiguity of interdisciplinarity", a safe space in which teachers and then students are welcome to experiment themselves as boundary people". The choreography, leveraging on the differences between humans' creativity and machines' creativity, represents a way to manage and value the equilibrium between "*sense making and strange making skills*". The interaction between teachers with different knowledge and expertise and how those teachers moved within the school's constraints to realise the AI atelier as an extra-curricular activity is also an example of how boosting educational institutions' motivation and creating and expanding the network for open schooling initiatives. The AI Atelier is also an example of how to search for locations and institutional contexts that can act as "third spaces", that is, spaces that do not belong to any disciplinary context but that are inhabited in safe and creative ways. These spaces should be suited to incorporate principles that can boost the activation of boundary-crossing mechanisms and a system of acknowledgment for "boundary skills". The atelier was in fact designed as an extracurricular activity that does not belong to any particular subject but within the school institution. The fact that the school hosts this interdisciplinary project emphasises that teachers could promote a cultural change in the educational institutions that aims to overcome a "binary perspective" (either disciplines or interdisciplinarity) and to boost "embracing uncertainty, ambiguity, sense of belonging. Furthermore, the third space created by the teachers suggests also that they could intertwine disciplinary professional discourses and attitudes valuing differences in methodologies and outcomes.

From the perspective of the research, there is still an analysis in progress of teachers' interviews aiming to understand how they interacted to create the third space, the characteristics of the choreography and of the third space they created, and how they moved from an institutional point of view.

FR2: the AI atelier contributes to analyse examples of contamination and cross the intersection of narratives in the nexus between art and science, in particular in comparing the machines' and humans' creativity. The scaffolding of the comparison proved to be effective to reflect on the implications of the digital world we live in and to envision a more ethical and sustainable relationship between humans and machines. WP2 also outlined an unbound framework for new languages (section 4). The choreography that teachers created, the mix of different disciplinary narratives that characterise it, and the philosophical layer foster students to create a personal language to discuss the key aspects of the relationship between humans and machines that characterise the contemporary debates reifying meanings to the unbound framework. The narrative of the geography as well as the final artworks are an example of languages for adaptation since they are rooted in the social dimension with the aim of unveiling the continuous changes at the bases of the society of acceleration, languages for uncharted territories since the intertwining between the world we live in and the digital one are explored through the interaction of generative algorithms, and languages for interdependencies since they embody a reflection about the relationship between human and artificial creativities and its connection with the contemporary debates.

Kairos - To correct the subtle drift of days

The design and delivery of Kairos in Italy have addressed mainly two out of three FEDORA frameworks.

FR1: Kairos referred specifically to three recommendations of FR1, that are, *(a) Practising interdisciplinarity is challenging to teachers and researchers; (b) Disciplinary isolation and lack of interdisciplinary language to talk across different perspectives; (c) Disciplinary knowledge organisation does not prepare graduates for work life and beyond.*

(a) The nature of the module automatically challenges the teachers involved to practice and deal with interdisciplinarity. Specifically, the physics and the literature teachers co-developed a trading zone, where disciplinary concepts were merged. They both designed a *choreography* that implies to borrow the words of the other discipline to talk about the proper discipline; in this case, the role of languages and their mutual relationship was crucial to involve also other teachers (the chemistry one) and the lab technicians. The outcome was a mixture of "languages" (words, formulas, simulations, experiments) which at the same time joined the teachers and the technicians, and gave back a unified picture of the concepts addressed.

(b) Grounding the lessons on the epistemology of disciplines helps to consolidate the "sense-making" skills; this was done in the initial physics lectures and in the lab sessions. On the other hand, the choice to ask students to write a theatrical piece, and the effort made by the teachers to map concepts from the literature field with concepts coming from physics, fostered the development of "strange-making" skills. The effort put by the teachers in helping students balance system/critical thinking (within disciplines) with creative/imaginative thinking (across disciplines), help students to question the meaning of disciplines and the ways the languages are allowed to talk about them.

(c) The choice of the scientific content (science of complex systems) as well as the teaching practices held in class, are aimed to help students in developing awareness of the complexity around them and the roles they can have as agents within a complex world (complex system). The epistemology of complex system highlights the role of prediction, cause-effect, emergent

phenomena, the value of interactions, as key factors to monitor and deal with when making sense of a phenomenon that is complex; because the physics teacher systematically and explicitly stressed the possible identification of students as agents, and their class/group/community/society as the complex system around them, the scientific epistemic practices that are used to make sense within science, are reported as epistemic practices to make sense in the *society of acceleration and uncertainty*.

FR2: the nature of the activity naturally embeds some issues and recommendations coming from the research addressed in D2.5. Indeed, the process of getting to know writing techniques, while respecting some boundaries (in the topic, in the structure), but also having a lot of freedom of expression, provided students the chance of an **immersive experience.** This process, which requires a long time, made of group writing sessions, alone writing sessions, class discussions about scenes, discussions with the teacher, took students to express **epistemic emotions** which seems to be powerful instruments to grasp with huge concepts as the ones brought by this complex society. Being trained to work with stories, and so exploit **metaphors** to talk about scientific concepts, increase the possibilities for students of making sense of the challenges they have to deal with in their daily life, such as sustainability, which in some cases result unintelligible with the ordinary scientific languages.

Simulations of complex systems

The design and delivery of this activity had the ambition to mainly address and elaborate on ***FR3*** framework.

FR3: The data analysis shows that, as other studies reported in FR3 showed, students struggle to grasp the change in their own perception and attitude toward the future after future-oriented activities. Even if different types of data showed that, in general, through the teaching activities, the students changed their way of perceiving the future (e.g. the future became closer to students' reach, more connected to local realities and space of action) and developed refined competencies to address a future-oriented problem, they were not always able to recognize the change that occurred or the same fact that a change occurred (see issue "Lack of metacognition in futures thinking" in FR3). This misalignment between the observed change and the narrative of change developed by the students deserves to be further investigated to make students active protagonists of their own learning, able to recognize the gain they can have from science future-oriented learning.

The second quantum revolution

The design and delivery of the AI atelier in Italy have addressed mainly two out of three FEDORA frameworks.

FR1: from the analysis of results, the activities proved to be prototypical to contribute to addressing some of the issues described in the deliverable especially concerning the disciplinary isolation and the lack of interdisciplinary language and graduates unprepared for life (D1.2, Framework for aligning science teaching and learning in formal educational contexts with the modus operandi of R&I). In particular, the activities proved fruitful in reflecting on disciplinary identities as well as their intertwining. These aspects should be thought about during the design and should be clarified during the activities' implementation in class. It is possible to design activities and find rational and epistemic narratives that can promote the shift from deterministic to probabilistic thinking, developing competencies to better grapple with contemporary society, manage the contingencies, and inhabit and embrace uncertainty. The narrative of the classical and quantum demon and its reconceptualization on the Voros' cone proved to be very fruitful. Furthermore, the activities could provide a prototype and principles that can orient the design of a "choreography" that can safely guide participants to accept the risk and embrace the ambiguity of interdisciplinarity.

FR3: addressing a STEAM topic, creating spaces to reflect on the implication not only on the dimension of the research but also on the political, economic, ethical, environmental, societal, and educational can help students to reflect on the possible roles of science and technology can play. The future-oriented activity like Eve's city and the scenario-building activity, after having unpacked the epistemic structure of the science content can, as described in D3.3: i. elicit students' scientific and technological images of the future ii. address ongoing and emerging trends in science and technology iii. highlight the role of human agency in the development of science and technology and sociotechnical change, iv. address and embrace complexity and uncertainty. The different activities can also be a pedagogical prototype for embracing emerging teaching using interdisciplinary projects, practising different types of futures thinking, deconstructing spacetime rituals in science classrooms, guiding the students to manage tensions and overcome polarizations and using collective group work to open up to alternative futures

Conclusions and suggestions for the FEDORA Model for Science Education from the implementations

Starting the design process in 2020, two rounds of implementations took place during the second and third years of the project. Overall, 18 implementations were conducted, involving more than 300 students, 50 teachers, 40 researchers, and a variety of other stakeholders in a diverse set of learning environments, both formal, non-formal and informal, including schools, universities, teaching-learning centres, and museums. The implementations addressed issues previously highlighted in FEDORA frameworks on interdisciplinarity, new languages and futures by creating teaching modules around themes such as the simulation of complex systems, quantum revolutions, the city of the future and climate change.

The main feature emerged from the analysis of this second round of implementations is the huge and deep variety of nuances touched by the materials and activities concerning the three FEDORA main pillars as well as the research issues investigated concerning the effectiveness of the materials in developing FEDORA-related skills.

The results of the second-round implementation appear very promising and will be furtherly deepened in publications, which are already in progress.

However, to conclude a general and summative reflection about these two rounds, as a synthesis from the whole operative scaffolding we can point out some overall findings which emerge from our research approach to the open-schooling design and practice and which characterise the dynamic dialogue between the FEDORA frameworks and their immersion into local experiences. These results have been also published in the FEDORA final handbook (Levrini et al. 2023) as main highlights from WP4, and they are:

- ***Inter-multi-transdisciplinarity can be the epistemological driver for institutional change.***

Dealing with inter-multi-disciplinary topics in schools implies creating “trading spaces”, where teachers and researchers are invited to inhabit an interdisciplinary context by exchanging aims and values, knowledge, practices, and methods of their disciplines. Co-designing prototypes of interdisciplinary topics can support the teachers in “making and unmaking boundaries” between disciplines. In this way, they have the opportunity to both shed light on disciplinary foundations and identities and re-generate subject matters to make them relevant from a societal, personal and vocational point of view. Teachers have the chance to shape new forms of professional collaborations and new forms of participation in the classes. Thus, enlarging the imagination about epistemic forms of knowledge organisation, and making boundaries and frontiers visible and crossable, can drive institutional changes.

- ***Inter-multi-transdisciplinary knowledge challenges the professional trait of teachers as unique experts. It triggers new models of co-teaching.*** The assumption that teaching needs to be grounded on new inter-multi-transdisciplinary knowledge organisation, poses new challenges to teacher preparation and teaching practices. Indeed, as shown in the first chapter of this handbook, to exploit the inner sense of interdisciplinarity, as well as to be consistent with the goal to align formal teaching with multi-actor and open research and innovation, new forms of co-teaching have to be imagined. The design and implementation of prototype activities inhabiting the boundary of STEM (Science, Technology, Engineering and Maths) disciplines and SSH (Social Sciences and Humanities) disciplines require questioning the role of the singular expert (teacher) and the cohabiting of a plurality of expertise. The project’s results highlight how interdisciplinarity allows to understand and solidify the position of an expert in the discipline but also implies redefining the role of an expert with respect to knowledge, colleagues (both the experts in the same discipline and others) and learners. Creating this co-design and co-teaching space turns schools into places where a plurality of professionals can collaborate to find ways to make the teaching experiences meaningful for the young. Reasoning in terms of co-design and co-teaching also questions their working schemes and the way in which instructional responsibility is distributed within this new complex space, where the specificity and the intersections of different disciplinary approaches emerge with mutual ownership, pooled resources and joint accountability.
- ***The discovery of disciplines’ inner meanings involves transiting and dialoguing with other disciplines.*** Several implementations involved STEM disciplines and arts, creating contexts in which young students could engage in an interdisciplinary project involving the authentic coalescing of languages. The establishment of a dialogue between disciplinary territories activated a process of translation from specific linguistic systems into others, creating the opportunity to enhance the communicability of STEM disciplines themselves. This process of translating scientific contents from one disciplinary language to another was intended to encourage a re-conceptualisation of the notions by clarifying and enriching their meaning and making them come alive in the search for personal meaning.
- ***Grappling with the uncertainty and complexity of futures thinking can act as an activator for “future-making”.*** For many students, it seems that the act of explicitly thinking about

future trajectories is somewhat unfamiliar. Consequently, teaching interventions can have a relatively high impact on students' outlooks and attitudes and their understanding of the futures. For instance, students may begin to conceptualise the future in a more positive and hopeful manner after dedicating time to envision desirable scenarios. By leading students to appreciate the complexity of the world, perceptions of uncertainty and openness may emerge. If given appropriate support and time to reconsider their implicit beliefs, students can transition from indisputable, hopeless futures with fixed mindsets towards exploring the future through the lenses of planning, choice, agency and catalysts for change. In this manner, our implementations illustrate ways of supporting and empowering students to shift from perceiving the futures as something that simply happens to them to considering themselves as active contributors in shaping it. Furthermore, by providing a space for a transdisciplinary consideration of the future, students may take steps to connect their disciplinary knowledge base and the complex nature of global challenges.

- ***The change in futures perception through future-oriented science education does not go hand-in-hand with the narratives of change developed by students.*** Studies have shown that students struggle to grasp the change in their own perception and attitude toward the future after future-oriented activities. Despite different types of data showing that, in general, through the teaching activities, students changed their way of perceiving the future (e.g. the future became closer to students' reach, more connected to local realities and space of action) and developed refined competencies to address a future-oriented problem, they were not consistently able to acknowledge that such changes had taken place. This misalignment between the observed change and the narrative of change developed by them deserves to be further investigated to make students active protagonists of their own learning, able to recognize the gain they can have from science future-oriented learning.

These highlights represented for us important milestones to build our "Model for science education for the Society of Acceleration and Uncertainty".

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