FEDORA

Deliverable 4.2

FEDORA materials effectiveness to develop thinking and future-scaffolding skills and to foster aware, responsible and proactive engagement with science: results and hypotheses from the first round implementations

FEDORA - Future-oriented Science EDucation to enhance Responsibility and engagement in the society of Acceleration and uncertainty
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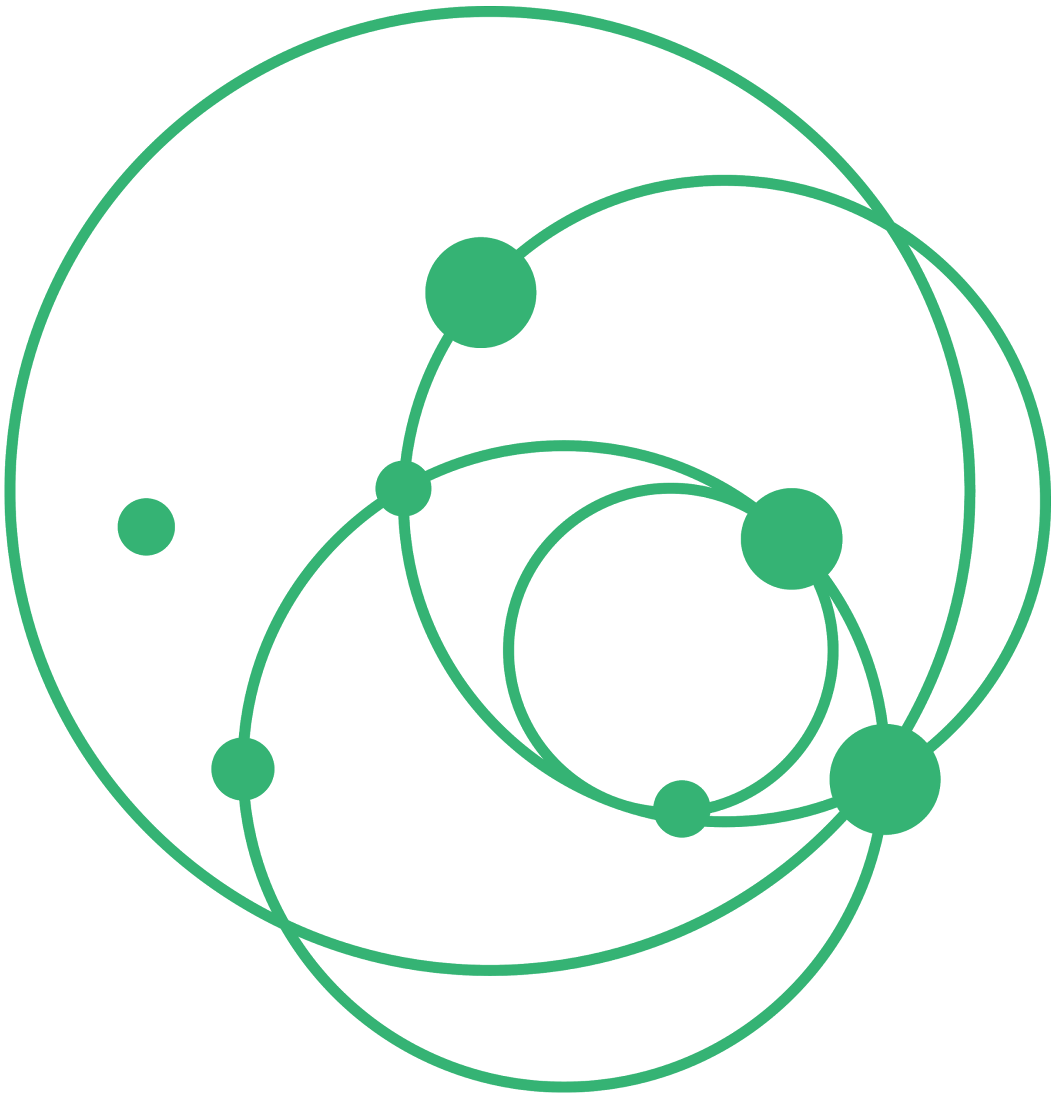
Quality assurance

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

OSNs	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
SDGs	Sustainable Development Goals
MoRRI	Monitoring Responsible Research and Innovation

Introduction

This deliverable has the aim to present the state of the first round of FEDORA implementations as well as the results achieved by them.

FEDORA's first round of implementations took place during the second year of the project 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). As foreseen by the project, one pillar action of WP4 is to design and implement innovative teaching activities and materials aimed to develop inter-multi-transdisciplinary, linguistic/argumentative, imaginative thinking and future-scaffolding skills and to impact young people's engagement with future-oriented and science-related activities. Specifically, the objectives pursued with WP4 actions were:

- Implement innovative teaching materials and activities that will be designed in light of the recommendations that will be produced in WP1, WP2 and WP3, about, respectively, forms of knowledge organisations, new languages and narratives and future-oriented activities;
- Investigate the processes of thinking (inter-multi-transdisciplinary, linguistic/argumentative, imaginative) and future-scaffolding skills development in 11-19 years-old people through the implementation of the above teaching materials and/or activities (GO4; SO7[1]);
- Investigate the impact of the above teaching materials and activities on: (i) young people's perception and attitudes toward the future, (ii) their ways to understand, react to and interact with science and scientific developments, (iii) their motives for engaging in science-related activities (GO4; SO8; SO9[1]).

Within WP4, the first year was devoted mainly to the establishment of the three OSNs in Finland, Italy, and the UK (the three developer/implementer countries).

From September to December 2021 the three local OSNs collected materials, activities and tools from previous projects and experiences, working in synergies with WP1-2-3 and establishing both the implementation plan and the research agenda. In January 2022, the WP4 committee organised a meeting of alignment for wrapping up the starting of the activity in the three OSNs and reasoning about research questions guiding the data collection and analysis of the first round of implementation. Finally, in January 2022, HOSN, OOSN, and BOSN started their first implementations as established in the plan, by respecting the variety of ages, gender, culture, and contexts promised in the proposal and by embedding, since the design phase, the capacity of the materials and activities to be diversity-responsive and consistent with the Sustainable Development Goals (specifically with SDG

[1] FEDORA general and specific objectives addressed by WP4:
GO4) Support the young generation to increase their personal and public engagement in science, their employability within a comprehensive view of "smart, sustainable and inclusive growth" (EC, 2015a; p. 30), and their hope, trust, desire, visionary and proactive moods in this accelerated, multi-velocity, complex and uncertain society.
SO7) To equip, through the implementation of the model in educational contexts, 11-19 years old people with *thinking (inter-multi-transdisciplinary, linguistic-argumentative-imaginative) and future-scaffolding skills* needed to navigate and participate in science within the society of acceleration.
SO8) To improve, through the implementation of the model in different educational contexts (formal, informal and non-formal), *scientific literacy*, *public engagement* and the quality of the ways young people understand, react to and interact with science, and *their motives for engaging in science-related activities*.
SO9) To nurture new forms of hope, desire, visionary and proactive moods by supporting and facilitating deep, authentic and aesthetic personal engagement in science as a fundamental asset to become active and responsible citizens in a changing and fragile world.

4.7, SDG 4.3, and SDG 4.4), as well as with the MoRRI indicators for Monitoring Responsible Research and Innovation (in particular SLSE 1 and SLSE 3).

This deliverable presents the process that guided the three OSNs toward the implementations as well as the data collected and an excerpt of the main results. Indeed, the single implementations were studied more in-depth for master and/or PhD thesis and/or research articles. Proper references are indicated in the text for the further interest of the readers.

Summary of the first round of implementations

In the first round, at least one implementation was carried out by each of the three OSNs, for a total of six implementations. In this chapter, we present the main features of all the 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

Six implementations were carried out in the OSNs. In particular, one was carried out by HOSN, one by OOSN, and four by BOSN. Three implementations were repeated more than once, in different contexts, for a total of 10 **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. 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)	Extended name of the implementation	No. of repetitions
HOSN-2022-CITY	My city of the future	1
OOSN-2022-MUS	Climate change at the museum	3
BOSN-2021-MOCK	Mocku for change	1
BOSN-2021-PHCL	Physics of clouds	1
BOSN-2022-SIM	Simulations of complex systems	2
BOSN-2021-QUAT	Quantum atelier and The second quantum revolution	2

For what concerns the **contexts** of the implementations, two of them took place only in-school settings (BOSN-2021–QUAT and BOSN-2021-PHCL), other two were conducted only out of school (OOSN-2022-MUS and BOSN-2021-MOCK), while the remaining implementations (HOSN-2022-CITY and BOSN-2022-SIM) 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 Natural Science Museum (OOSN-2022-MUS).
The **time duration** of the implementations varied a lot across the OSNs, as depicted in Figure 1. They range from a minimum of 6 hours for the experience in the museum (OOSN-2022-MUS) to a maximum of 50 for the course "Physics of Clouds" (BOSN-2021-PHCL). In total, considering the repetitions of the implementations, the first round resulted in more than 200 hours of teaching-learning experiences.

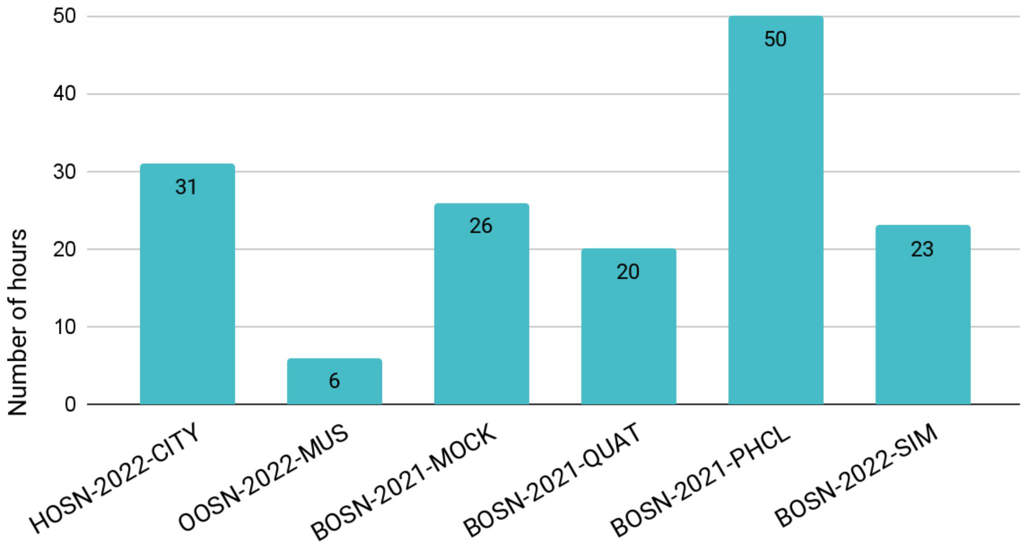

Fig. 1. Number of hours for each implementation.

All implementations were mainly targeted at secondary-school **students** (15-19 years-old). In total, more than 160 students participated in the first-round implementations (89 males, 78 females, 1 identifying as he/they); in Figure 2, we report the gender distribution of the participants. We need to stress that only for three implementations (HOSN-2022-CITY, BOSN-2021-MOCK and BOSN-2022-SIM) explicit information was collected on participants' *perceived gender*, asking the participants to fill in a questionnaire without assuming their gender. As we will remark in the Conclusions, this issue will be addressed more systematically in the second round of implementations.

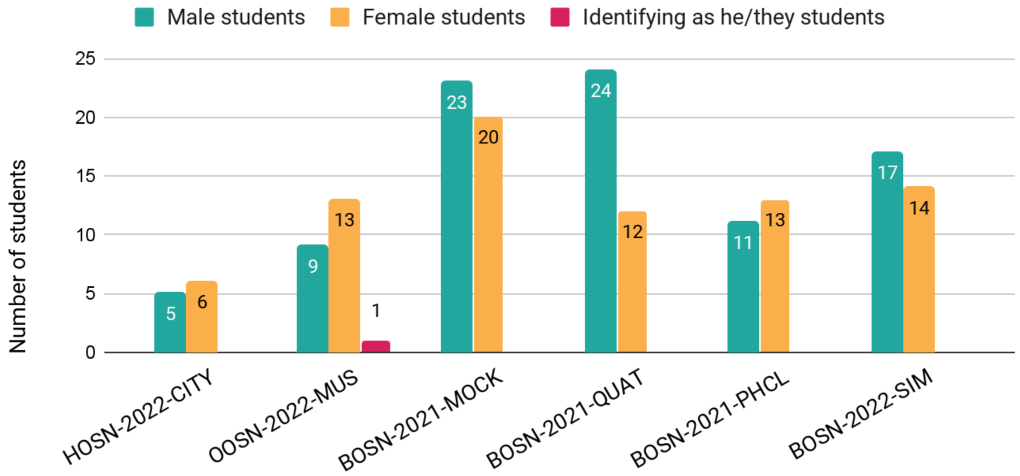

Fig. 2. Numbers of students in each implementation.

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

- 32 **in-service teachers** (16 males, 16 females);
- 23 **researchers** (12 males, 11 females);
- 11 **additional stakeholders**: 5 pre-service teachers (3 males, 2 females), 1 museum educators (female), 1 research facilitator (female), 1 video-maker (female), 1 expert in climate negotiations (female), 1 environmental design expert (male), 1 head of city Climate Unit (female).

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 balanced across the implementations. Indeed, each pillar was addressed by 5 different implementations.

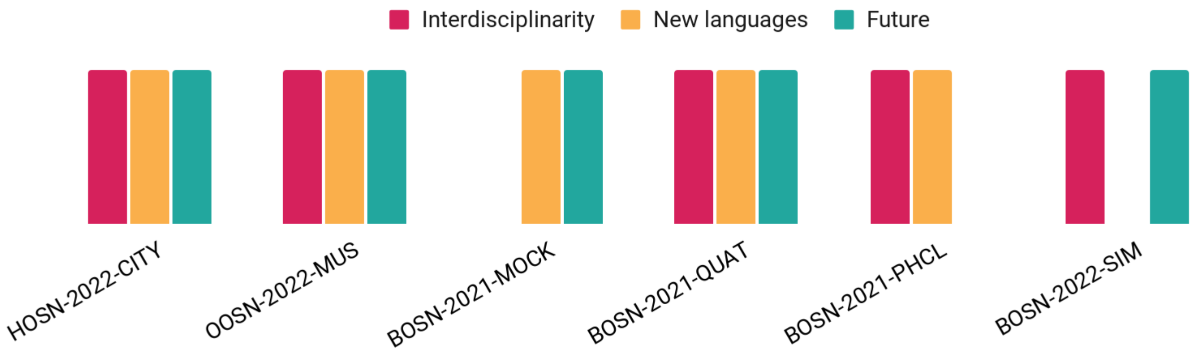

Figure 3. FEDORA's pillars addressed in each implementation.

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 emphasis on the interconnections of jobs and professional roles to address collective

challenges
- The recognition of the roles of disciplines that are studied in school curricula to tackle interdisciplinarity
- The widening of STEM to STEAM to include arts and humanities

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
- The exploitation of artistic genres (e.g., mockumentary and creative writing) to support science teaching and learning

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

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 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 2. Details on the implementation "My city of the future", carried out by HOSN.

"My city of the future" (HOSN-2022-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), February-April 2022
Total number of hours	11 hrs + 20 hrs of group work
Participants	Students (16-18 y.o.): 5 males + 6 female In-service teachers: 1 male + 2 females Researchers: 1 male + 2 females Environmental design expert from the city of Helsinki Climate Unit: 1 male Head of the city of Helsinki Climate Unit: 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	Yes. We ensured 50/50 representation of female and male experts/policymakers/researchers that the students interacted with. Furthermore, all students were given equal opportunities to voice their hopes for policymakers.
Forms of students' participation foreseen	Yes. The students had a lot of autonomy in how they approached and worked with the central course tasks.
List of main scientific topics addressed	Energy production; Carbon neutrality; Technology; Transport
Relationship with FEDORA pillars	• Interdisciplinarity (WP1) • New languages (WP2) • Future (WP3) The course was explicitly transdisciplinary: the main issue was the complex system of the city. Perspectives taken included energy, climate, and the sociocultural and political spheres. The language-widening approaches applied in the course design included discourse (especially through legitimate interaction with the city), imagination (through future writing activities) and so on. For example, in the post-course interviews, a student noted how usually technology is discussed in a solution-oriented way, but the course made them aware of a new critical discourse. Finally, 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.

Brief overview of the activities implemented	1. Introduction to 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. 2. Students worked on their visions for Helsinki in the year 2050, writing evocative future descriptions in small groups. 3. The texts were continually challenged by the teachers as well as three invited consulting experts (smart city anthropology, values in futures thinking, energy and sustainability transitions). 4. The students also built timelines between today and their vision, mapping central actions to take to reach their desired future, paying special attention to systemic perspectives and the role of science and technology in creating sustainability (e.g. energy production) and shaping the city of the future (e.g. new technologies). 5. The students familiarised themselves with the publicly available "Carbon Neutral Helsinki 2035 Action Plan", guided by a pedagogical workshop on analysing values and assumptions in future scenarios, after which they met with one of the Action Plan's authors to discuss the rationale for the environmental policies of the city of Helsinki. During these activities, students compared their own thinking with official policies and contrasted the actions they wished to see taken with those currently planned or executed. 6. Finally, guided by the teachers of the course, the students collected their own visions in a small pamphlet. The course ended with a discussion panel between our students, the head of the Helsinki city Climate Team and other students from the school in the audience, during which we handed the finalised pamphlet over to the city.
Types of data collected and tools	● Pre-post test SenseMaker ● Student group interviews with the working groups of the course: 4 interviews of 2-3 students each were carried out. ● Students' written essays on future visions (& the final pamphlet) and their evolution over the course, guided by instructions given throughout the course.
MoRRI indicators touched	SLSE 1
SDGs addressed	SDG 4.7; SDG 4.3; SDG 4.4

Climate change at the museum

Table 3. Details on the implementation "Climate change at the museum", carried out by OOSN.

"Climate change at the museum" (OOSN-2022-MUS)		
OSN and city	OOSN	Oxford
Context	Out-of-school	Informal/Non-formal
Brief description of the context	A Museum of Natural History in England was selected as the informal teaching space for the needs of this study. The workshop was organised in	

	the context of a Youth Advisory Board activity, which included a school trip to the museum and a visit to a local university. During the museum visit, one class from two regional schools attended a three-hour workshop that was led by two members of the research team and one museum educator. All the participants of this study had voluntarily selected this workshop as their preferred learning activity within the Youth Advisory Board.
Period of time and frequency	June 2022 (one workshop per school)
Total number of hours	3 hours per school = 6 hours
Participants	Students (15-17 y.o.): 9 males + 13 females + 1 identifying as he/they In-service teachers: 2 male + 4 females Researchers: 1 male + 1 females Museum educator: 1 male Research facilitator: 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	Yes. Although this was not the focus of the workshop, we included a video depicting male and female experts from various disciplines discussing climate change. Shortly after the video, we asked students to reflect on the experts' identities. The discussion led to the discovery of the idea of multidisciplinarity and inclusion in research.
Forms of students' participation foreseen	Yes. We included presentations (with PowerPoint slides and museum artefacts), whole-class discussions and within and between groups discussions/presentations.
List of main scientific topics addressed	Climate change: Causes, consequences and future scenarios
Relationship with FEDORA pillars	• Interdisciplinarity (WP1) • New languages (WP2) • Future (WP3) WP1: The teaching materials and the student activities included future scenarios that demonstrated the power of collective and personal actions. These actions were discussed in relation to the interdisciplinary nature of climate change in STEM as well as the multiple professions and roles that each discipline touches. In this way, students were able to see the interconnections between professions, causes and actions with regard to climate change. WP2: The museum was selected because of its focus and interest in climate change and biodiversity activities, which would serve as the basis of the designed lesson. For instance, examples of workshops and exhibitions regarding climate change hosted by the museum were presented and discussed during the teaching session. In this context, an explicit mention of the role that arts and other 'languages' can play in understanding and discussing global issues, such as climate change. WP3: Given that this study emphasised the *development of possible and probable future scenarios* and the *selection of preferable future(s)*, a set of cards illustrating climate change-related scenarios were introduced. The cards were co-developed with two science teachers and were categorised into

	'positive' and 'negative' or 'troubled' future scenarios. This categorisation was based on whether or not actions would be taken to address climate change in the future.
Brief overview of the activities implemented	1. Students visited the museum and a brief introduction to artefacts was conducted by a museum educator 2. PowerPoint presentation & videos: What is climate change? How does what happens now differ from what happened in the past, and why? 3. Whole-class discussion: What are the underlying causes for these changes? 4. PowerPoint presentation: How might climate change affect the future? 5. Student group work: Students were divided into 'positive' and 'negative' scenario groups of 3 to 5 participants. Within their groups, students were asked to rank out of 12 the five most important scenarios. During the group discussions, students were encouraged to reflect on the importance of the presented scenarios on a collective, as well as on an individual level. 6. Student presentations: Students presented their rankings in teams. All teams asked questions and discussed similarities and differences between the rankings.
Types of data collected and tools	• Student questionnaires • Audio files (student group work & student post-test interviews)
MoRRI indicators touched	SLSE 1; SLSE 3
SDGs addressed	SDG 4.7

Mocku for change

Table 4. Details on the implementation "Mocku for change", carried out by BOSN.

"Mocku for change" (BOSN-2021-MOCK)		
OSN and city	BOSN	Bologna (online)
Context	Out-of-school	Formal
Brief description of the context	Extra-curricular course for university orientation (PLS - Scientific Degrees Plan), organised at the Department of Physics and Astronomy.	
Period of time and frequency	2021 November-December, once a week, 7 times in total	
Total number of hours	21 + 5 (homework and asynchronous tasks)	
Participants	Students (16-18 y.o.): 23 males + 20 females In-service teachers: 4 males + 3 females Researchers in science education: 2 females PhD students in science education: 2 males + 1 female Full professor expert in climate change: 1 male Expert in climate negotiations: 1 female Video-maker: 1 female	
Collection of explicit information on the gender of	Yes	

the participants	
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. Each student was encouraged to choose and play a specific role within their group, according to their skills, attitudes and desires: screenwriter/camera operator/editor/director/actor.
List of main scientific topics addressed	Climate change; Complex systems
Relationship with FEDORA pillars	• New languages (WP2) • Future (WP3) The "Mocku for change" implementation encouraged students in imagining and creating their desirable or undesirable future scenarios by experimenting with a new language, specifically the cinematic language in the form of the mockumentary genre.
Brief overview of the activities implemented	1. Introduction to climate change: models, impacts and action strategies (Prof. Antonello Pasini, CNR Rome); 2. Introduction to cCHALLENGE (Dr. Giulia Tasquier, UNIBO in collaboration with cCHANGE, Oslo) 3. Experiments on examples of radiation-matter interaction (Dr. Giulia Tasquier, Unibo) 4. Experiments for the construction of a model for the greenhouse effect (Dr. Giulia Tasquier, Unibo) 5. Introduction to complex systems: modelling and simulations (Dr. Eleonora Barelli, Unibo); 6. Analysis of texts, conversion into causal maps and identification of feedback (Dr. Giulia Tasquier, Unibo) 7. Political and economic scenarios: role play on negotiation (Dr. Eleonora Cogo, CMCC Bologna and Dr. Giulia Tasquier) 8. Videogame on climate change (Dr. Eleonora Cogo, CMCC Bologna and Dr. Giulia Tasquier) 9. New languages for science communication and Introduction to the Mockumentary genre (Emma D'Orto, Unibo) 10. Laboratory meetings for the production of mockumentaries 11. Interactive lesson in the form of a Film Festival (Giulia Tasquier, Emma D'Orto, UNIBO)
Types of data collected and tools	Both qualitative and quantitative data were collected by the means of: • Questionnaires • Lesson observation • Artefacts collection
MoRRI indicators touched	SLSE 1; SLSE 3
SDGs addressed	SDG 4.7

Physics of clouds

Table 5. Details on the implementation "Physics of clouds", carried out by BOSN.

"Physics of clouds" (BOSN-2021-PHCL)		
OSN and city	BOSN	Rimini
Context	In-school	Formal
Brief description of the context	Extra-curricular course held during curricular hours at the A. Einstein scientific high school in Rimini. The course is targeted at 15-year-old students.	
Period of time and frequency	2021 March-May twice a week	
Total number of hours	Approximately 50 hours	
Participants	Students: 11 males + 13 females In-service teachers: 2 females	
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. Even if we did not set up them in an explicit way, the aim of the activity was to write, in groups, stories with a scientific theme. The mode of storytelling is in itself engaging and should allow everyone to find their own way of participation. Lessons were also interactive.	
List of main scientific topics addressed	Complex systems and their main properties	
Relationship with FEDORA pillars	• Interdisciplinarity (WP1) • New languages (WP2) Writing short stories with a scientific theme as a narrative structure, requires bringing the constraints of physics and those of creative writing into play. There is a close interdisciplinarity between scientific and humanistic disciplines. It also requires the construction of appropriate language to express scientific concepts in the story.	
Brief overview of the activities implemented	1. *Interactive lecture*: an introduction to some fundamental concepts characterising complex systems. The lecture was given by maths and physics teacher 2. *Workshop*: the students, divided into groups, had to take pictures, around the city, to document situations and contexts that might have the characteristics of a complex system 3. *Interactive lecture*: presentation of the material produced in the workshop and discussion of the concepts covered.	

	4. *Interactive lecture*: clarification of some properties of complex systems. The lecture was given by the maths and physics teacher. 5. *Interactive lectures:* critical reading of the short story collection Palomar by Italo Calvino during curricular hours throughout the second half of the school year. The lessons were taught by the literature teacher. 6. *Interactive lecture:* critical reading of the short story "Reading a wave" in Palomar from the perspective of complex systems. The lecture was given by all the teachers 7. *Interactive lectures:* lecture introducing the rules and the constraints of creative writing 8. *Workshop:* short story writing. The students, divided into groups of four, wrote short stories 'in several hands', documenting their work in a logbook. The writing session took place with constant interaction with the teacher.
Types of data collected and tools	Six short story writing (essays)
MoRRI indicators touched	SLSE 1; SLSE 3
SDGs addressed	SDG 4.7

Simulations of complex systems

Table 6. Details on the implementation "Simulations of complex systems", carried out by BOSN.

"Simulations of complex systems" (BOSN-2022-SIM)		
OSN and city	BOSN	Bologna (online)
Context	Out-of-school (2021) In-school (2022)	Formal
Brief description of the context	This module 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. A further implementation was carried out by the teachers of the IESS lyceum of Reggio Emilia (Emilia Romagna, Italy), in collaboration with UNIBO researchers. It was carried out during school time in the context of a STEM laboratory.	
Period of time and frequency	2022 January-February, once a week, 6 times in total 2022 May, twice a week, 6 times in total	
Total number of hours	18 + 5 (homework and asynchronous tasks) for PLS implementation 20 for IESS implementation	
Participants	PLS implementation: Students (16-18 y.o.): 9 males + 7 females In-service teachers: 3 males + 2 females	

	Researchers in science education: 2 males + 2 females Full professor expert in computational physics: 1 male Early career researchers in Physics or Astronomy: 3 males + 1 female Pre-service teachers: 3 males + 2 females IESS implementation: Students (16-18 y.o.): 8 males + 7 females In-service teachers: 1 male + 1 female Researchers in science education: 1 male + 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. 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., the physical modelling, the mathematical formalism, the computational implementation, the domain-specific characteristic of the system under study) to make as many students as possible feel at ease.
List of main scientific topics addressed	Agent-based simulations; Complex systems; Computational aspects of scientific modelling
Relationship with FEDORA pillars	● Interdisciplinarity (WP1) ● Future (WP3) The topic of computational simulations is addressed as an interdisciplinary and future-oriented topic. Indeed, it lies at the interface between physical modelling, mathematical formalisation, and computational implementation but also social sciences. It has a future-oriented character since simulations allow the students to experiment with a virtual laboratory in which many possible scenarios of the future evolution of many types of systems can be obtained.
Brief overview of the activities implemented	1. *Lectio magistralis*: "Computational physics in the era of big data" 2. Ice-breaking activity and round table with early career researchers: "Simulations as research tools" 3. Interactive analysis of agent-based simulations of complex systems 4. Activity of analogies' development: "From models of systems to real problems" 5. Group activity of construction of scenarios based on simulations 6. Groups' presentations and conclusion
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
SDGs addressed	SDG 4.7; SDG 4.3; SDG 4.4

Quantum atelier and The second quantum revolution

Table 7. Details on the implementation "Quantum atelier and The second quantum revolution", carried out by BOSN.

"Quantum atelier" and "The second quantum revolution" (BOSN-2021-QUAT)		
OSN and city	BOSN	Rimini
Context	In-school as extra-curricular activities	Formal
Brief description of the context	The Second Quantum Revolution: PLS extra-curricular course at Liceo Scientifico A. Einstein, Rimini As a follow-up of PLS course: Quantum Atelier, an extra-curricular course at Liceo Scientifico A. Einstein, Rimini	
Period of time and frequency	October 2021 (twice a week) November 2021 - April 2022 (once every two weeks)	
Total number of hours	20h (The Second Quantum Revolution) 20h (Quantum Atelier)	
Participants	The Second Quantum Revolution Students (18-19 y.o.): 21 males + 9 females In-service teachers: 3 males + 1 female Quantum Atelier Students (18-19 y.o.): 3 males + 3 females In-service teachers: 2 males + 1 female Researchers: 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	No	
Forms of students' participation foreseen	Yes. We set up different forms of participation such as collective discussions, focus groups, teamwork activities, and workshops.	
List of main scientific topics addressed	The Second Quantum Revolution and its societal impact; Physics of quantum technologies	

Relationship with FEDORA pillars	• Interdisciplinarity (WP1) • New languages (WP2) • Future (WP3) The course on the Second Quantum Revolution touch all these three themes. The theme of interdisciplinarity is the matrix of the course. Quantum technologies are a STEM topic and, throughout the activities, on the nature of the disciplines (in particular physics, computer science and mathematics) and their intertwining. The theme of the future is addressed by valuing the epistemic structure of quantum physics, in particular, the ideas of possible states, measurement and intrinsic probability, linked with the possible future scenario, future thinking, contingencies management and probabilistic thinking. Furthermore, a reflection on the impact of quantum technologies on the present and on the future is carried out with different kinds of activities The theme of the new languages is addressed by leveraging on the idea that, even if quantum technologies are deeply investigated and researched, they are not part of a collective imaginary. There is a cultural need of finding narratives and aesthetics to talk about the second quantum revolution. The Quantum atelier was a space of genuine interdisciplinarity between art and science. The translation of scientific concepts was not done in purely illustrative terms. It was decided to proceed according to the terms of what could be considered an artistic translation.
Brief overview of the activities implemented	1. Overview of the scope and the impact of the Second Quantum Revolution on society, research, politics, economy,... 2. History of classical computers and classical logic: toward the physics theory of information 3. Introduction to the basics concepts of quantum physics (quantum state, superposition principle, state manipulation/evolution, measurement) from an experimental to a computational perspective. 4. Introduction to the basics concepts of quantum physics (entanglement) and BB84 quantum cryptography protocol. 5. Teleportation protocol from an experimental to a computational perspective. 6. Introduction to future studies (the future cone and the concept of scenario related to quantum technologies). 7. Teamwork to reflect on the relationship between humans-science/technology, nature-humans and science/technology-nature. 8. Reflection on the research of new languages and narratives (art) to interpret the historical and present revolutions. 9. Quantum Atelier: reflection on the most revolutionary concepts, and reconceptualization of them through artistic languages and production of final artworks.
Types of data collected and tools	• Teamwork questionnaire • Recoded focus group • Recoded collective interview • Students' description of their artworks
MoRRI indicators touched	SLSE 1; SLSE 3
SDGs addressed	SDG 4.7; SDG 4.3; SDG 4.4

Preliminary 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.

Research questions addressed

As we have anticipated in the introduction, before the first round, the three OSNs converged on a research agenda of possible questions that would have been explored through the implementations. Figure 4 shows a map of the research questions (RQs) organised per area, i.e. Interdisciplinarity, Future, New Languages, Agency, Sense-Making & Strange-Making, Epistemic Identities & Emotions,.. .

Figure 4. Overview of the research agenda.

During the first round, the RQs were refined so as to be more and more focused on the features of each implementation. Table 8 includes the main RQs addressed by each implementation. We highlighted 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 8. Overview of the specific RQs addressed in the implementations.

HOSN - "My city of future"	- How do students' future stories portray the development of systemic thinking and conceptualizations of the city, its biosphere, societal organisations, and built environments? - How do these conceptualisations of a city and the connections between the conceptualisations develop during the course?
OOSN - "Climate change at the museum"	- How does a scenario-based teaching session influence students' agency and their perceived futures literacy regarding climate change? - How does a scenario-based teaching session influence students' epistemically-related emotions and future actions with regard to climate change?
BOSN - "Mocku for change"	- To what extent the mockumentary genre can inspire and help students overcome the "imaginative and cultural failure that lies at the heart of the climate crisis" (Amitav Ghosh)? - How far can mockumentary work as a tool to foster the development of linguistic, argumentative and imaginative skills needed to picture "imaginative yet realistic" climate change scenarios?
BOSN - "Physics of clouds"	- Is it possible to construct a formal "shared space" in which an authentic dialogue between scientific and humanistic disciplines can be experienced? - Can the "translation process" of scientific content from one language (the scientific one) to another (the narrative one), encourage a re-conceptualization of these concepts by clarifying and enriching their meaning? - Does this interdisciplinary activity help thinking about the common meaning of epistemic emotions? - Can epistemic emotions trigger a deeper connection between students' self-construction and the epistemology of the discipline?

BOSN - "Simulations of complex systems"	- How did the students put into play future-scaffolding skills during the future-oriented activity? - How the future-scaffolding skills can be operationalized in the context of a future-oriented activity about the analysis of a complex topic through agent-based simulations? - Which future-scaffolding skills and interdisciplinary competencies do the students verbalise at the end of a future-oriented and interdisciplinary module?
BOSN - "Quantum Atelier" and "The second quantum revolution"	- Does the Second Quantum Revolution, and its interdisciplinary nature, provide a new coherent scenario that can promote the understanding of the essential quantum concepts and, at the same time, inform and prepare the new generations for the Quantum future? - How can the "revolutionary" significance of concepts of quantum revolutions be expressed with the language of the visual arts (with its constraints and its expressive potential)?

Methodologies for the design and analysis of the implementations

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, that will also involve the second round.

Concerning this first 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 preliminary results achieved

Each implementation has been analysed in separate studies or is in a process of advanced analysis. Some analyses were also already published in papers and/or chapters of theses as well as presented in some dissemination contexts. At the end of the deliverable, the references for the individual studies are reported (see Original research that contributed to this Deliverable).

For the scope of this deliverable, we summarise in Tables 9-14 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

Table 9. Results achieved in "My city of the future" (HOSN-2022-CITY).

Brief excerpt of results	**Highlights on the effectiveness of the materials**
The analytical results of both the students' interviews and their future stories showed a positive outcome in students' development and learning during the course. The future learning course was well received by the students, and they were eager for a similar course to be offered again. The data gathered during the course showed distinct signs of development in the students' future and systemic thinking skills, creating a more complete and sustainable understanding of the multitude of variables creating and impacting change, such as agency, science and technology. Through this progression made during the course, the students were also empowered in realising how they could create change. The extent of the topics discussed in the students' future stories ranged far beyond the topics covered during the course, showing how the course worked as an excellent framework upon which students could build their own futures including matters of importance from outside the walls of the classroom.	The data gathered during the course showed distinct signs of development in the students' future and systemic thinking skills, creating a more complete and sustainable understanding of the multitude of variables creating and impacting change, such as agency, science and technology. Through this progression made during the course, the students were also empowered in realising how they could create change. The extent of the topics discussed in the students' future stories ranged far beyond the topics covered during the course, showing how the course worked as an excellent framework upon which students could build their own futures including matters of importance from outside the walls of the classroom.

Climate change at the museum

Table 10. Results achieved in "Climate change at the museum" (OOSN-2022-MUS).

Brief excerpt of results	**Highlights on the effectiveness of the materials**
The results from the pre-test ($M = 3.5$, $SD = .51$) and the post-test ($M = 3.8$, $SD = .49$) indicated that the teaching session had a significant positive effect on students' climate agency, $t(22) = 2.1$, $p < .05$.	Students indicated a **low general engagement** with the topic, as the majority of them indicated that they have never or nearly never engaged in climate change activities during the year in which the study was conducted. Students **did not believe that schools** are providing them with the **skills necessary** to address future challenges. During student interviews, some students highlighted the importance of education about climate change from an early age.

The data analysis demonstrated that there was a significant improvement in students' perceived futures literacy (*M* = 4.5, *SD* = .74) compared to the pre-test (*M* = 3.8, *SD* = .74), t(22) = 3.3, p =.004.	After the session, the majority of the students held **positive views** about learning in informal spaces, such as **museums**. The session has **significantly impacted students' feeling of agency** towards climate change**,** as well as their **futures literacy**. A larger impact on students' confidence in **identifying some of the consequences of climate change**, as well as their belief that they can **take some action** against climate change. A larger impact on students' **ability to imagine positive scenarios** as a result of actions against climate change as well as their ability to **identify steps needed** to achieve a sustainable future. Students reported that during the session they felt **'motivated'** and **'hopeful'**, but also 'surprised'.

Mocku for change

Table 11. Results achieved in "Mocku for change" (BOSN-2021-MOCK).

Brief excerpt of results	Highlights on the effectiveness of the materials
The mockumentary language appeared to have the potential to work both as a thinking tool to enhance students' imagination and reflection and a linguistic tool to foster their self-expression by a re-shaping of knowledge that is linked to epistemic emotions, personal feelings and personal thoughts. The artistic constraints of the mockumentary genre helped students in picturing "imaginative yet realistic" scenarios, by inserting a large range of specific climate change features into realistic narrative scenarios (realistic people and stories) and in overcoming some typical polarisation attitudes related to Climate Change. The main one addressed is the polarisation "Fiction/Non-fiction" (intrinsically related to the mockumentary genre), but 3 other polarisation attitudes - in accordance with the results of climate change education research (Barelli et al., 2022; Tasquier, Knain & Jornet, 2022) - were taken into account: "Individual/Collectivity", "Reflection/Agency",	Mocku for Change was an interdisciplinary experience at the boundary between cinema and climate science. The activity was a prototype and the related data analysis had an exploratory character. This means that the methods of data analysis that have been chosen mainly aimed at "capturing a signal" that can reveal something about the potential of this form of language. The activity was generally well received and students declared they participated with interest and perceived the activity as "transformative" in terms of "meaningful to change ideas and emotions about Climate Change". Six among seven groups demonstrated to have appropriated some linguistic skills, i.e. some basic mockumentary visual/stylistic techniques and narrative modes producing a coherent product despite their unfamiliarity with the genre before the activity. On one side, it looks like the mockumentary genre helped in enhancing students' imagination and their feeling of agency and awareness of Climate Changes consequences.

"Simple/Complex". To analyse students' polarisation attitudes, a two-phase analysis was conducted, consisting of a post-vision questionnaire and a marker analysis of the videos. Most videos were able to overcome those polarisations by translating them into a more balanced tension between the two poles. Specifically, the more balanced videos were also the ones more coherent with the mockumentary genre.	It achieved this by creating narratives about both realistic future scenarios and present scenarios that show examples of the kind of choices we should take (or not take) in the present in order to lead us towards a desirable (or undesirable) future. However, the activity was characterised by a detachment from the disciplinary dimension and a large amount of freedom given to the students during the video-making process (a choice that is related to the exploratory character of the study). Some more in-depth exploration of the character of the genre was probably needed in order to let some more articulated argumentation and reasoning emerge from the final audio-visual narratives.

Physics of clouds

Table 12. Results achieved in "Physics of clouds" (BOSN-2021-PHCL).

Brief excerpt of results	**Highlights on the effectiveness of the materials**
The creative writing activity intertwined with the physics of complex systems represents a chance to enhance the communicability of physics discipline in itself. Indeed the writing meets very specific disciplinary contents as the ones within physics of complex systems, it can be used as the rhetoric of science, a tool, a new language to enhance the meaning. This is allowed by the translation process, a fruitful practice embedded in this kind of activity which "export" the meaning of science from its field and "import" it in a totally different field, forcing a reconceptualization of the contents. The spatial structure of the physics of complex systems has played the role of "scaffolding" to reformulate urgent questions related to the search for one's own identity in a dynamic relationship between "I" and "we" (between individual and collective). The epistemic emotions traced, acted as triggers to the scaffolding action of epistemology since they thematized emotions of the self with contents of physics.	The initial qualitative analysis shows that the conceptual tools linked to the epistemological framework of complexity developed in a "shared space" of genuine dialogue between disciplines have favoured: • balancing systemic and analytical thinking with imaginative and creative thinking • managing epistemic emotions more actively, grasping their nuances without polarising them into positive and negative emotions • managing tension between the desire to seek independence and self-affirmation and the fear of leaving the group

Simulations of complex systems

Table 13. Results achieved in "Simulations of complex systems" (BOSN-2022-SIM).

Brief excerpt of results	Highlights on the effectiveness of the materials
The future-oriented activity based on simulations is particularly suitable to develop structural future-scaffolding skills that in previous implementations were difficult to observe into action (Levrini et al., 2021). However, a remarkable misalignment can be observed between the future-scaffolding skills put into play by the students and what they actually verbalised of their development.	The future-oriented activity based on simulations is particularly suitable to develop future-scaffolding skills. In particular, the structural future-scaffolding skills were difficult to observe in action in previous implementations, while in the module on simulations they were directly recognizable in students' ways to perform the concluding activity. To measure the effectiveness of the module with respect to the development of future-scaffolding skills, we not only traced the skills into action when students performed their task, but also interviewed them at the end of the course to check their metacognition about the development of these skills related to the course attended.

Quantum atelier and The second quantum revolution

Table 14. Results achieved in "Quantum atelier" and "The second quantum revolution" (BOSN-2021-QUAT).

Brief excerpt of results	Highlights on the effectiveness of the materials
The experiences of the Second Quantum Revolution and the Quantum Atelier seem to have promoted deep understanding processes. Reflecting on different representations during the activities proved to be fruitful to trigger personal sense-making processes across different disciplines involved. The FEDORA activities, indeed, seem to have helped students to deepen the disciplinary objects, alienate them from the pure context of explanation and move/translate them into other contexts such as the artistic one. Particularly, the interdisciplinary nature of Quantum Atelier leads also students to learn how to conceptualise and re-conceptualise, dismantling and reassembling knowledge, trying to find a balance between different disciplinary constraints (the scientific and the artistic	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

ones: i.e. the formal and rigorous physics concept and the aesthetic form) as well as a balance with the limits of realisation based on personal skills. The production of the artworks suggested also that students learnt to "work" the knowledge, that is to look at it from different points of view and try to balance "contents and forms of knowledge" becoming aware also about the personal framing toward knowledge, how to manage and manipulate it according also to personal tastes and their personal identity. Even if the experiences proved to be personally and collectively effective and fruitful for personal learning and to start to rethink the relationship between art and science, the focus of the artwork was the concepts of the first quantum revolution enhancing the need to find new narratives to talk about the contemporary science to make people perceive more deeply the scope of the revolution.	Integrated fostering students to recognize different perspectives (e.g. disciplinary identities) and make connections between them (*interdisciplinary skills*). The future-oriented and citizenship education activities promoted the development of *responsible and proactive engagement with science and society* and *agency*. The Quantum Atelier promoted the development of *systemic* and *analytical thinking* and their *balancing* as well as *imaginative* and *creative thinking*.

Conclusions and suggestions from the first to the second round of implementations

The main feature emerged from the analysis of the first 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 first-round implementation appear very promising. However, from a methodological perspective, some observations can be sketched to orient the conduction of the research activities for the second round.

The first observation regards the type of methodologies for data analysis that were used. For many implementations, the skills developed by the participants were emphasised. However, the first-round implementations lack types of analyses oriented to **capture the process of competencies' development**, as well as the local changes induced by the activities carried out. For answering not only "which" but "how" learning occurs when related to interdisciplinarity, new languages, and futures, special attention will be devoted to microgenetic methods (Siegler, 2006). To allow an analysis able to monitor and unpack the process beyond what happens, a **redesign of the data collection and assessment tools** will be undertaken. For example, the three OSNs are planning to build a research instrument based on the concept of the "Narratives of change" (Bengtsson et al., 2020) able to follow the transformative process across personal and collective stories.

Another comment concerns a misalignment observed between the design and analytical phase in the first-round implementations related to gender and diversity issues. At the level of design of the teaching-learning settings, several principles to promote inclusivity were considered (see General overview for details). However, the compliance of materials and learning environment to the diversity and inclusion issues was not reflected in the phase of the analysis of data collected, in which no analysis was carried out to explicitly investigate gender differences or to empirically test the diversity-responsiveness of the materials. For the second round, the **gender and inclusion dimension** will be **strengthened** also **at the analytical level**.

The third observation that we can stress relates to the **frameworks that will feed the second-round implementations**. In addition to the specific theoretical and research accounts that pertain to the single implementations, the design of the activities conducted in the second round will be shaped by the knowledge base produced so far in FEDORA that is summarised in the three frameworks ("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", "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", "Framework to futurize science education"). Another framework that will feed the following implementations is the GreenComp, the new European sustainability competence framework (Bianchi, Pisiotis & Cabrera Giraldez, 2022). Indeed, two out of four of the competence areas of the framework (i.e. *Embracing complexity in sustainability* and *Envisioning sustainable futures*) are at the core of the FEDORA project. Indeed, on one side examples taken from the GreenComp of how to develop and monitor knowledge-based attitudes and skills can be inspirational for FEDORA; on the other side, FEDORA is inspiring with its practices coming from the implementation examples that can feed, nurture and further develop the GreenComp. The concrete interaction with this framework is already in due course thanks to the collaboration with the GreenComp's authors happening in (past and future) official events related to the project and it is part of FEDORA impact.

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