FEDORA

Deliverable 4.4

Model for science education for the Society of Acceleration and Uncertainty

Due date: 2023/08/31
Actual submission date: 2023/08/31
Project start date: 9/2020 (36 months)
Workpackage concerned: WP4
Concerned workpackage leader: UNIBO
Task leader: UNIBO
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Dissemination level:

- Public

FEDORA - Future-oriented Science EDucation to enhance Responsibility and engagement in the society of Acceleration and uncertainty
This project received funding from the European Union's Horizon 2020 Research and Innovation program under Grant Agreement n° 872841
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Acknowledgement:
All the FEDORA partners who contributed to the development of the back-and-forth dynamic among the WPs that contributed to create the FEDORA "Model for Science Education".
For the BOSN, we would like to thank:

- Elenora Barelli, Paola Fantini, Francesco De Zuani, Emma D'Orto, Sara Satanassi who were authors of D4.2 and D4.3 and contributed to the design and analysis on the italian implementations
- The teachers and the principals of the two core schools involved in the activity of the network, Liceo Scientifico A. Einstein (Rimini) and ITAER F. Baracca (Forlì).

For the HOSN, we would like to thank:

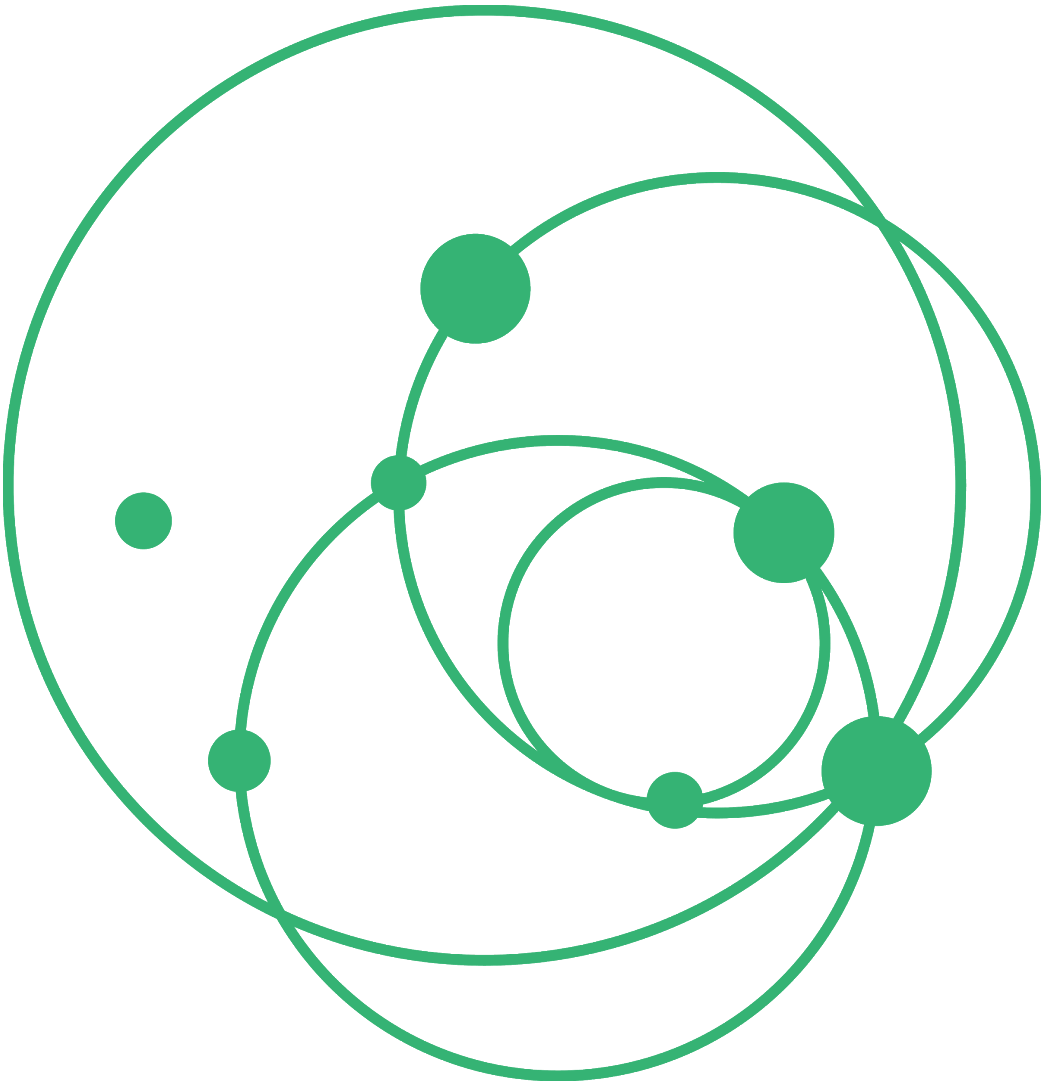
- teachers co-designing the FEDORA implementations in Helsinki: Pauliina Kuokka, Hanna Ylä-Mella and Panu Viitanen.
- experts contributing to the FEDORA implementations in Helsinki: Tommi Ekholm, Karoliina Isoaho, Meeri Karvinen, Tero Koivunen Johanna Yli-Pulli and Antti Rajala.

FOR the OOSN we would like to thank:

- Sibel Erduran and Olga Ioannidou who shaped up the OOSN and produced the booklet that consolidated the approach in the network
- Leanne Hughes and Judith Curtis from Holme Grange School; Sam Harper from the Social Sciences Division; Liam Guilfoyle, Alison Cullinane and Claire MacLeod from University of Oxford; and Sarah Lloyds from the Museum of Natural History in Oxford for their contributions to the related projects
- The ESRC IAA programme (Grant no. 2205-KICK-810; Project FutuRISE) for facilitating the acceleration of the impact of the FEDORA Project.

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
This deliverable contains original, unpublished work except where clearly indicated otherwise. It builds upon the experience of the team and related work published on this topic. Acknowledgement of previously published material and others' work has been made through appropriate citation, quotation, or both. The views and opinions expressed in this publication are the authors' sole responsibility and do not necessarily reflect the views of the European Commission.



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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
WP5	FEDORA Work Package 5: Recommendations for proactive and anticipatory policy-making
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

Executive Summary

This deliverable presents the research-based “**Model for science education**” for the society of acceleration and uncertainty developed within WP4 "Toward a model for science education for the society of acceleration and uncertainty".

The FEDORA “**Model for science education**” results from a back-and-forth-dynamic among WP4 and WP1-2-3 and is operatively constituted by: i) highlights emerged by the three FEDORA frameworks FR1-2-3 elaborated within WP1-2-3 which produced some recommendations that oriented the materials design of future-oriented, inter-multi-trans-disciplinary and multi-languages materials; ii) open-schooling and co-teaching practices that established the dynamic through which the materials were implemented; iii) emblematic case studies which illustrates how the model appeared in practice.

The model is summed up in the FEDORA handbook[1] presented to policymakers at the FEDORA event carried out in Brussels at M34. The handbook represents a textual and infographic synthesis of the three FEDORA frameworks FR1-2-3 in relation to main results emerged by WP4 and WP5.

This document is articulated in three main sections:

- The first section includes highlights from the three FEDORA frameworks, which represents the synthesis of the FEDORA theoretical approach to science education; this synthesi contain principles and recommendations;
- The second section includes highlights of the FEDORA open schooling networks, which represents the synthesis on how principles and recommendations of the three frameworks were operatively turned into practice and guided the design and implementation of teaching materials, but also the creation of interdisciplinary, multi-actor contexts and the implementation of co-teaching and open-schooling models;
- The third section illustrates three FEDORA emblematic case studies, taken from the implementations, which represented three core concrete achievements of the project.

This document is the fourth and last deliverable of WP4, led by University of Bologna.

[1] The full version of the handbook is available here: https://www.fedora-project.eu/wp-content/uploads/2023/07/Fedora_HandBook_v11.pdf

Introduction

This deliverable presents the research-based "**Model for science education**" for the society of acceleration and uncertainty developed within WP4 in interaction with WP1-2-3.

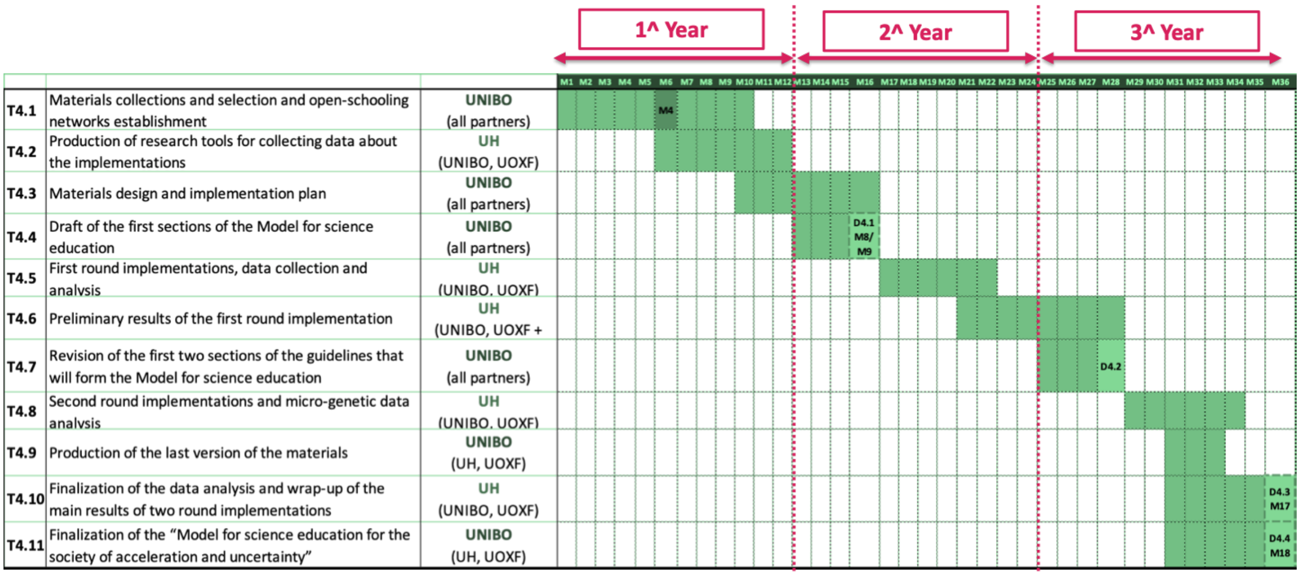
The objectives pursued with WP4 actions were:

- 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[2]);
- 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]);
- Develop theoretical constructs or framework able not only to describe what happens in a specific innovative teaching/learning experience but also to provide an interpretation of why, when and how that happened (GO4; SO6[1]);
- Develop models of co-teaching and open-schooling needed to implement future-oriented, inter-multi-transdisciplinary materials and multi-languages materials;
- Develop guidelines to renew science education targeted to science education researchers, teachers, educators in formal, non-formal and informal contexts and aimed to bridge the three forms of misalignment that FEDORA analysed in WP1, WP2, WP3 (GO1; GO2; GO3; GO4; SO6[1]).

WP4 pursued these objectives by carrying out **11 tasks**, achieving **5 milestones** and delivering **4 deliverables**.

The following image summarise the flow of WP4 activities across the three years of the project:

[2] 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.



During the first year of the project, FEDORA's open schooling networks were established in the three developer/implementer countries (BOSN - Bologna Open Schooling Network; HOSN - Helsinki Open Schooling Network; OOSN - Oxford Open Schooling Network). The networks represented the places where both theoretical and empirical activities were put into action. Theoretical reflections and results coming from the first year of the project converged into deliverable D4.1, which represented a milestone for coordinating the researches carried out in WP1, WP2 and WP3 and turning them into orientations and executive suggestions for fundamental actions in WP4: establishing local open schooling networks, designing the activities and planning the implementations.

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 (BOSN; HOSN; OOSN). The main results coming from these implementations converged into deliverable D4.2, which aimed to showcase the main results but also find a point of convergence among the OSNs and the FEDORA main pillars (WP1-2-3).

FEDORA's second round of implementations took place during the third year of the project, always within the three open schooling networks established in the developer/implementer countries (BOSN; HOSN; OOSN). The main results coming from these implementations converged into deliverable D4.3, which aimed to showcase progress results carried out during the second and last round of implementations and also to stress how FR1-2-3 were put into practice.

Lastly, this document is not only a follow-up of deliverable D4.1 - aimed to draft the first chapters of the FEDORA model for science education and guide the implementations - but mainly an overall synthesis of WP4 in its interaction with the three FEDORA frameworks FR1-2-3 aimed to settle how the FEDORA "**Model for science education**" was elaborated throughout the project and, in particular, throughout two rounds of implementations of materials and activities. This document is targeted at science education researchers, teachers, educators in formal, non-formal and informal contexts, science communicators and professional institutions with science education and communication in their mission.

It is articulated in three main sections:

- The first section includes highlights from the three FEDORA frameworks, which represents the synthesis of the FEDORA theoretical approach to science education;

this synthesi contain principles and recommendations;

- The second section includes highlights of the FEDORA open schooling networks, which represents the synthesis on how principles and recommendations of the three frameworks were operatively turned into practice and guided the design and implementation of teaching materials, but also the creation of interdisciplinary, multi-actor contexts and the implementation of co-teaching and open-schooling models;
- The third section illustrates three FEDORA emblematic case studies, taken from the implementations, which represented three core concrete achievements of the project.

Highlights from the three FEDORA frameworks

The core concept of the FEDORA project grounds on three misalignments which define the **three main blind spots** in Science Education addressed by the project. The ***first blind spot*** refers to the need to revise the institutional, methodological and conceptual organisation in traditional disciplines in order to align school science with the *inter-multi-transdisciplinary*, *multi-actor* and *open* characters of R&I. The ***second blind spot*** refers to the need to explore *new languages and narratives* to enable the young generation to grapple with the complexity of the current societal challenges and to participate in the current debate valuing the points of view of scientific communities. The ***third blind spot*** refers to the need to “futurize” science education. This implies the need to infuse education with activities able to provide the young with future-scaffolding skills that enable them to construct visions of the future that empower action in the present with an eye on the horizon.

Within the project organisation, the three blind spots were respectively addressed within WP1, WP2 and WP3, that represented the three main pillars of the project. Each of them worked across the project in different ways to deeply enter and unpack the three very diverse blind spots however with some synergies, needed to coordinate the impact of their results in relation to WP4. The progressive refinement of the work addressed within WP1-2-3 crossed three very important steps, happening at M12, M26 and M34.

The first main results of the research works carried out in WP1-2-3 were, indeed, reported in the deliverables submitted at M12:

- **D1.1 -** First draft recommendations on “forms of knowledge organisation for co-teaching and open-schooling” for the design of materials
- **D2.2** - First draft of recommendations on “new languages” for the design of materials
- **D3.1** - First draft of recommendations for the design of materials to futurize science education.

The second main results consisted of the production of the three final frameworks FR1–2-3 reported in the deliverables submitted at M26:

- **D1.2 - 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
- **D2.5 - 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
- **D3.3 - FR3** - Framework to futurize science education.

Those three frameworks are comprehensive of the issues emerged from the different studies carried out within the three WPs and, respectively, the issues are addressed by a set of recommended ways to tackle them.

The last step was characterised by the effort to put together a synthesis of this large and intense work into a handbook presented to policymakers at the FEDORA carried out in Brussels at M34. The handbook represents a textual and infographic synthesi of the three FEDORA frameworks in relation to main results emerged by WP4 and WP5.

FR1-2-3 represented for FEDORA a three-pronged research-based evidence on which the "**Model for science education**" is founded.

Inspired by the synthesis of the handbook, in the following we report research-based highlights concerning the three frameworks[3].

FR1 highlights

Educational systems, with their tradition of vertical and hyper-specialised organisation in disciplines, are challenged by the need to equip the young with competencies to deal with inter-multi-transdisciplinary issues. The guiding questions addressed within WP1 were: *How can we model inter-multi-transdisciplinarity and design "boundary spaces" in formal and informal educational contexts? What institutional, epistemological, cultural, and emotional barriers can interdisciplinarity encounter?*

Led by Kaunas University of Technology together with the contribution of the University of Bologna, some theoretical and empirical studies (i.e. literature review, interviews, study groups and surveys) were conducted aiming to identify the limits and advantages of disciplinary knowledge organisation and the boundaries or barriers that pose to the advantages of inter-/multi-/trans-disciplinarity in science education.

FR1 elaborated the following set of recommendations aiming to strengthen science education and equip young people with interdisciplinary thinking and future-scaffolding skills. They are:

- At the political level, **re-engineering governance and changing institutional processes** must take place: key performance indicators, funding formula of research-performing organisations, adding qualitative criteria to quantitative ones in the criteria of staffing, coordination, performance assessment, and workload allocations have been previously identified as the prerequisites to ensure the sustainability of interdisciplinary courses. Remodelling criteria for evaluating research must occur: the guiding point is not "ease of evaluation" but the importance of the research problem and impact on society that the research will produce, which is promoted by strategic programming documents at EU and national levels.
- At the community level, **human resource management practices** have to be revisited: adding qualitative criteria to quantitative ones in the criteria of staffing, coordination, performance assessment, and workload allocations has been recommended by prior research as the prerequisites to ensure the sustainability of interdisciplinary courses. Emphasis on collaboration at the institutional level may contribute to maintaining teacher teams with the mindset of co-ownership of interdisciplinary courses and securing a stable **core teaching team** with a mindset of co-ownership of interdisciplinary courses. Developing **supporting materials** such as data sets, lesson

[3] These recommendations belong to the handbook but for in depth details, the whole frameworks are available here: https://www.fedora-project.eu/deliverables/.

templates, local and international case studies, and hands-on activities and experiments may add to the effects of institutional changes.

- At the individual level, a "disciplinary nomad" coping strategy may facilitate overcoming cognitive and epistemological barriers and enacting interdisciplinarity. To enable boundary crossing at this (identity) level, institutions should facilitate the development of **a common interdisciplinary language.** Focusing on the problem that a course helps to solve rather than on different approaches and languages of dissent can help to cross experienced cognitive and epistemological boundaries.
- The recommendation above leads to the community-level approach again, indicating the need to establish a **"third space",** be it a physical or a virtual one, that is free of disciplinary metalanguage and symbols to enable interdisciplinarity. At schools, changes to interdisciplinary teaching and respective reconfiguration of a learning space may be mutually reinforcing and contribute to the development of individual freedom and group creativity.
- In the contexts of shared languages and co-teaching, the search for a common language may happen by managing an equilibrium **between sense-making skills** (systems, critical, analytical thinking) **and strange-making skills** (creative, imaginative, anticipative thinking) besides managing tensions between belonging-nonbelonging, defining-negotiating meaning, going in-out of a comfort zone, zooming in-zooming out (from details to big pictures and vice versa). These processes encourage individuals to accept intellectual risks, embrace ambiguity and learn scientific uncertainty. Besides, introducing philosophy (of science) as a compulsory discipline is seen as helpful for educating students for life as it promotes broader views. Balancing informal education organised by formal educational institutions may contribute to developing skills needed for working life.
- Educational institutions as communities of practice may rely on **curriculum differentiation,** rather than pedagogical differentiation, as a response to the diversity of students' abilities to make different knowledge available for different groups of students, as indicated by prior studies. Overall, terms used in different disciplines have to be defined and agreed upon by the community of learners and teachers.

FR2 highlights

As global citizens, we face challenges that need our attention, creativity and intention to stimulate visions of desirable futures. There is a recognised need for new languages and formats to enhance imagination and the capacity to talk about them and find ways to describe, define, and face them with creative solutions. The guiding questions addressed within WP2 were: *How to create innovative ways to communicate, foster and imagine?*

Led by Formicablu, a benchmark study and two creative workshops that gathered experts from different disciplines were conducted aiming to search in the language ways to accept, interpret and embrace ambiguity, complexity and uncertainty as permanent states of reality that need to be addressed in a way that gives a sense of agency and influence, not only for students but also for teachers and the array of professionals and workers of society.

FR2 proposed four key concepts that can convey four types of languages, able to navigate unexplored territories and possible futures, and convey actions in our uncertain times. They are:

- **Languages for adaptation: they relate to evolution**

- **Languages for foraging futures: they relate to time**
- **Languages for uncharted territories: they relate to space**
- **Languages for interdependencies: they relate to interactions**

The framework explains the sources and flows underpinning the co-creation of new languages. A linear trajectory transitions into a multidirectional one. It avoids a prescriptive recipe. Therefore border lines are open and organic, considering this representation “unbounded”. Languages “yet to become” embrace a constellation of desirable traits, and they consider space, time, evolution and interactions for envisioning the future while grasping and activating the present.

FR3 highlights

The global sustainability crises and the accelerating societal and technological development demand science education to address students’ concerns and uncertainty towards the future. The guiding questions addressed within WP3 were: *How do young people perceive their personal and global futures*? How do they imagine the role of science and technology in those futures? How can science education foster students’ futures thinking and agency?*

Led by the University of Helsinki together with the contribution of Teach the Future and the University of Bologna, some theoretical and empirical studies were conducted aiming to investigate young people’s perceptions of the future, students’ futures thinking and links to futures thinking skills in European science curricula for secondary schools.

FR3 elaborated the following set of recommendations aiming to address problematic issues and limitations in students’ futures thinking, connect futures thinking skills to scientific and technological skills and knowledge, and address related aspects of educational design and school culture. They are:

- *(Why, for whom?)* – **General aims for science education. Recommendations especially for policymakers, curriculum developers and teacher educators.**
    a. Use futures thinking to cross, connect and contextualise 21st-century skills
    b. Incorporate future concepts and elements in science curricula
    c. Incorporate futures thinking in science teacher education programs
    d. Understand and address the personal, gendered, cultural, religious, socioeconomic and political dimensions of futures thinking and related beliefs
    e. Foster the development of future-scaffolding skills

- *(What?)* – **Contexts and contents of science education. Recommendations primarily for local-level curriculum developers, teachers, teaching material developers and teacher educators.**
    f. Elicit students’ scientific and technological images of the future
    g. Address ongoing and emerging trends in science and technology
    h. Highlight the role of human agency in the development of science and technology and sociotechnical change
    i. Address and embrace complexity and uncertainty

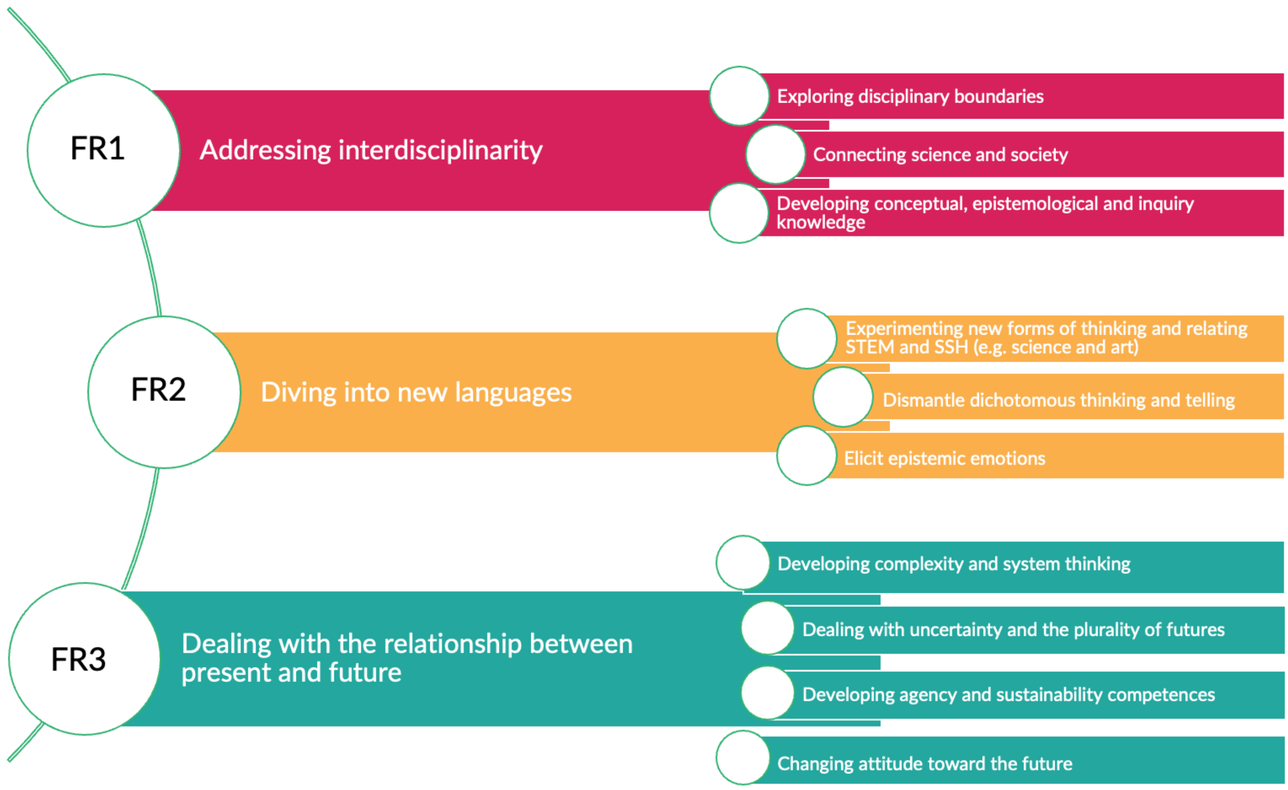
- *(How?)* – **Pedagogical methods in science education. Recommendations especially**

for teachers, teaching material developers and teacher educators[4]**.**

j. Embrace emerging teaching using interdisciplinary projects
k. Practise different types of futures' thinking in the classroom
l. Deconstruct spacetime rituals in science classrooms
m. Guide students to manage tensions and overcome polarisation
n. Use collective group work to open up to alternative futures

These results constitute a groundwork for future-oriented science education that provides students with tools for deeply connecting with and finding agency within their personal and global futures.

During the second round of implementations, the recommendations elaborated within FR1-2-3 guided the design of some learning outcomes that were explicitly used to refine the materials and the RQs formulated for each study (see deliverable D4.3). The following picture gives an exemplary overview of some general learning outcomes related to FR1-2-3.



Open Schooling within FEDORA

The establishment of the open schooling networks (OSNs) in FEDORA started since the beginning of the project and has been coordinated through a series of consortium activities.

[4]See the Future-Oriented Science Education Manifesto, that is also available here: http://bit.ly/fedoramanifesto).

Such activities have been designed to share the concept of open schooling and establishment principles (Tasquier et al., 2021).

The concept of open schooling was introduced in FEDORA from the very beginning and was shared at the consortium level during the FEDORA kick-off meeting (29-30 October 2020).

FEDORA took inspiration from existing models of open schooling proposed by different EU projects (e.g. Tasquier et al., 2023) and, especially, the model of open schooling (https://thisisopenschooling.org/) elaborated within the Horizon2020 SEAS project[5].

Briefly summarising, the open schooling idea was officially introduced within the EU context in 2015 by the report entitled «*Science Education for A Responsible Citizenship*» (2015) which asserts the need to create and explore ways to expand science education beyond traditional school models. As stated in the report, open schooling implies that schools cooperate with other institutions and organisations to achieve community well-being and change the way science comes into the classroom. Particularly, the concept of 'openness' refers to the idea that schools must become flexible structures, open to society and able to make a difference in the world (EU, 2015). The SEAS project interprets the EU spirit by intending the concept of 'openness' in a broader sense. It refers to an effort to open up traditional schooling to:

A. **include and reinterpret education content** that is not commonly included in education, as well as scientific, disciplinary perspectives;
B. **include non-traditional stakeholders** in schooling and actors associated with traditional schooling to engage with actors outside of schooling;
C. **connect school learning with** that which is traditionally considered **outside** the issue of schooling (Bengtsson, S., Jornet Gil, A., Van Poeck, K, Knain, E., 2020).

Taking into account the three FEDORA frameworks (FR1-2-3), the definition of 'openness' has been interpreted within FEDORA in terms of possible dimensions of action, whose departure points are: Act at a level of content (A); Act at a level of interaction among the various stakeholders in interdisciplinary and multi-actor contexts and open schooling networks (B); Act at a level of (institutional) transformation (C).

Operatively, the progressively turning of the principles into actions and feeding back from the actions to the principles was carried out within WP4 activities.

The first year of the project led the partners to understanding what it meant to create an open schooling network within the FEDORA project and what characteristics a network related to the three main pillars of the project should have. Local contexts were also studied to understand how to build an authentic network, enhancing relationships, projects, etc. already existing.

To do this, in the first year there was an alternation of meetings at a global level of WP4 and at a local level of core groups of work for the three developer/implementer countries (Finland, Italy, UK) to explore the situation, understand which stakeholders to involve and how to structure the network. Initially the work of sharing what an open schooling network meant was discussed by the SMB board where a representative per partner was always present, this allowed to understand and share the basis at the consortium level. The discussion about open schooling went on within the SMB meetings, between October and December 2020, where the consortium reflected about the open schooling idea and its evolution from the EU Report toward the SEAS project. From January to April 2021, the three developer/implementer countries started to explore, at local level, possible implementation contexts, existing

[5] SEAS - Science Education for Action and engagement towards Sustainability (GA No. 824522, September 2019 – August 2022). PI: Erik Knain, University of Oslo (https://www.seas.uio.no).

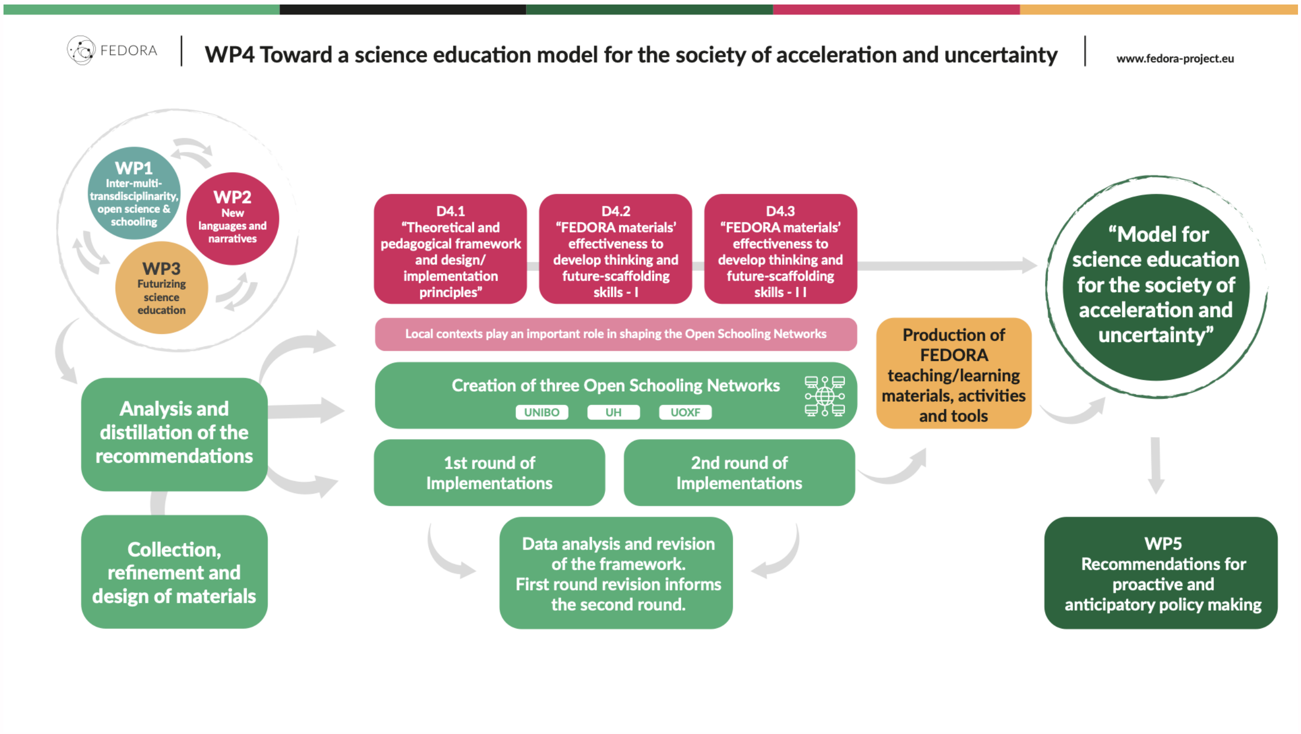
collaborations, stakeholders, materials, tools of data collection. In April 2021 WP4 committee was established with at least two members from each developer/implementer country . The committee met up regularly for sharing materials, activities, tools of data collection and for aligning local and global progress about WP4. In June 2021, during the second consortium meeting, there was an important moment of alignment among the consortium (WP4 committee, SMB and all the partners) as well as among WP4 activities and WP1-2-3 recommendations. The consortium meeting represented an important chance to agree about interactive strategies to follow and plan next steps. Finally, from June to September 2021, each local network planned the official establishment and launch of the local open schooling network. Three Open-Schooling Networks (OSNs), respectively in Bologna, Helsinki and Oxford, were in charge of producing prototypes or models to align science education with fast-changing science and society. Based on the recommendations from the three FEDORA min pillars, they were settled as multi-actor and multi-stakeholder structures involving STEM[6] and SSH[7] researchers, researchers in science education, science educators (teachers, communicators, philosophers and historians of science, scientists, science communicators), language experts (video-makers, bloggers, writers, data story-tellers), experts in futures studies, sociologists, artists, citizens, entrepreneurs, NGOs and students.

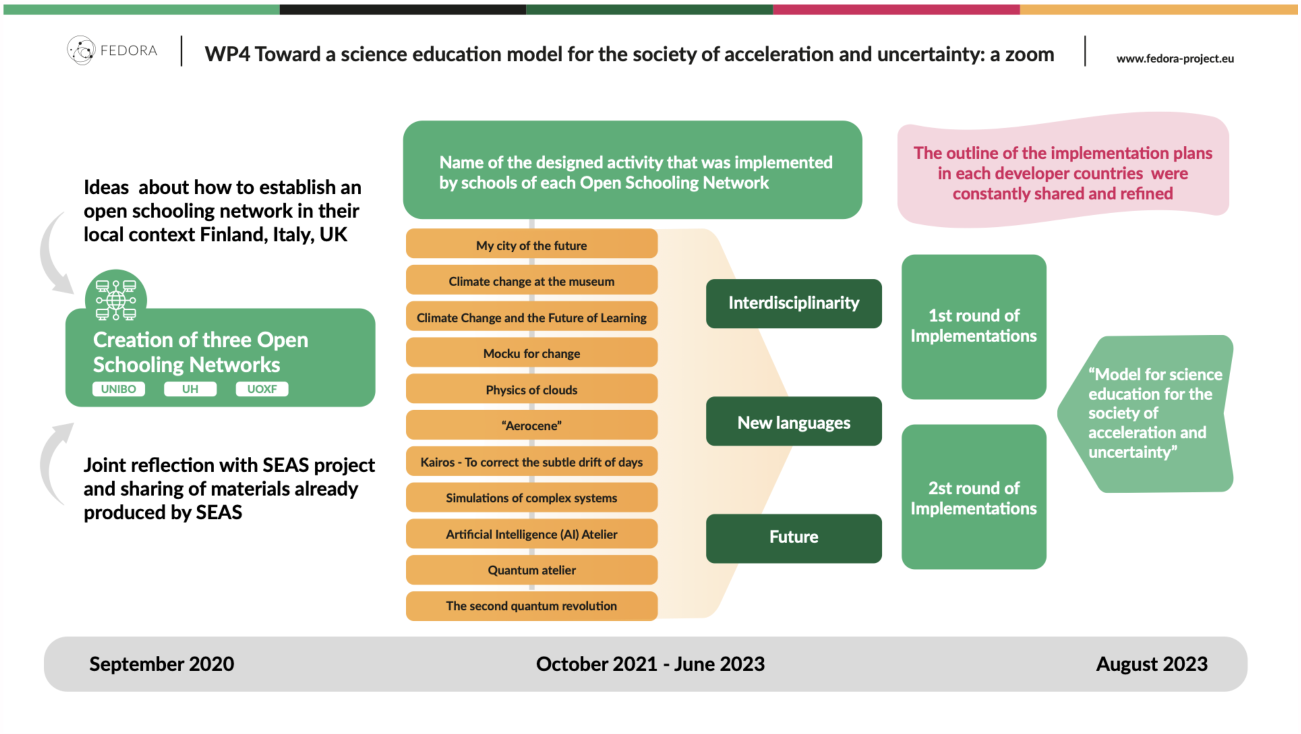
The second year of the FEDORA project (from September 2021 to August 2022) represented the moment of planning, designing, implementing and analysing the first round of FEDORA's implementations. Across the second year, **6 different types of FEDORA teaching/learning experience** were designed and implemented **10 times** in very different contexts. Those implementations were analysed and highlights of results were officially published in D4.2 (Tasquier et al., 2022). In September 2022, during the third consortium meeting, there was another important moment of alignment among the consortium (WP4 committee, the three OSNs coordinators and all the partners) as well as among WP4 results from the first round and the progress of the three frameworks developed in WP1-2-3. The consortium meeting represented an important chance to: reflect back on the first round of implementations; identify idiosyncratic features of the OSNs and synergies among them; agree about interactive strategies to follow for taking in consideration feedback on the results and plan the second round. Across the third year, **7 types of FEDORA teaching/learning experience**, some of them refined from the first round and some of them completely new, were built and implemented **9 times**.

Overall, **19 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 following infographics produced for the handbook, summarise WP4 dynamic and activities:

[6] Science, Technology, Engineering and Maths
[7] Social Sciences and Humanities





The Bologna Open Schooling Network

The Bologna Open Schooling Network (BOSN) was a follow-up and re-definement of the community of practice and the open schooling network established in previous projects. Indeed, the starting point of the BOSN was the experience of designing innovative approaches and teaching modules to foster students' capacities to imagine the future and aspire to STEM careers that occurred from September 2016 to August 2019 within the Erasmus+ project I

SEE[8]. This experience fed the open schooling network established in September 2019 within the SEAS project[9]. In particular, FEDORA borrows from SEAS **the heuristic model of the *three spheres of transformation*** (O' Brien and Sygna, 2013) as a means for understanding the changing relationship between individual, collective, and political agency. According to this model, the change concerns three different interconnected spheres: a *practical sphere* (linked to behaviour), a *political sphere* (linked to institutional and system aspects) and a *personal sphere* (linked to values, worldviews, etc). The practical sphere includes technical and behavioural changes. The political sphere highlights the systems and structures that facilitate or impede transformations in the practical sphere, and include the social norms, rules, regulations, institutions and infrastructure that define how society is organised. The political and practical spheres in turn are influenced by the (inter-) personal sphere, which highlights the importance of individual and collective worldviews, values, beliefs and paradigms that are at stake and which drive people's motives for practical and political action. This model was used in the network to define the way in which science enters the schools and the schools open toward society.

For one year, the two networks overlapped and collaborated jointly by taking some common structural features and differentiating some others according to the different aims of the two projects.

Across the three years, the BOSN brought together more than 30 individuals who are: **researchers in physics, mathematics and STEM education** (senior and junior, among which post-doc, PhD, graduate and master students); **secondary school teachers** in physics, mathematics, natural sciences, humanities from different schools (scientific lyceums; technical schools; international school; dance, music and theatre high school); school **principals**; **science communicators** with different expertise (blogger, video-maker, planetarist, writers and data story-teller); **researchers in hard sciences** (e.g. climate scientists,...), **philosophy** (analytic and philosophy of science) and **linguistics**; expert in **future studies**; professional in **international political negotiations** and author of a video-game on climate change; **policymakers and advisory experts** who participated in planning, evaluation and revision of the teaching/learning activities. The core group of the networks was composed by a group of researchers and a group of implementing teachers who represented the engine of the life and continuous dynamic of the network.

Due to the high variety of the expertise and people involved in the networks, we had several initial meetings to brainstorm, share and analyse values and needs, barriers and problems as well as the positioning with respect to the FEDORA main themes with the aim to build a map of synergies where to build upon and ground the network.

For the design and the implementation of the FEDORA activities, a key dynamic occurred since the beginning in the way the BOSN functioned. Encompassing the idea of open schooling to create and explore ways to expand science education beyond traditional school models, in FEDORA, we adopted co-designing and co-teaching as methodologies (Härkki et al., 2021; Levrini et al., 2023; Maranzano, 2023; Vesikivi, 2019) to introduce a number of interdisciplinary topics (like climate change and artificial intelligence) in high schools and to implement new rituals of science teaching. This collective work on interdisciplinary topics represented a fundamental feature of the BOSN which also guided important discussions related to the **redefinition of the role of the teacher** in terms of relationship with knowledge, fields of competences and consolidated practices, school constraints and colleagues. This was

[8] https://iseeproject.eu
[9] https://www.seas.uio.no/about/local-networks/italian-local-network/index.html

shown and largely discussed in the results published in D4.2 and D4.3 (Tasquier et al., 2021; 2023).

The Helsinki Open Schooling Network

The Helsinki Open Schooling Network (HOSN) established during the FEDORA project brought together a diverse group of educators, researchers, policymakers and other experts. The network includes 19 individuals in four overlapping clusters. These are: 3 **researchers of the FEDORA project** (who are also tied in with policymaking and implementing the local FEDORA module); 3 **implementing teachers** of Helsinki Upper-Secondary School of Natural Sciences; 6 **substance experts** who took part in the implementation (and advised in the planning); and 7 **policymakers and advisory experts** who participated in planning, evaluation and revision of the module.

For the implementation of the module, a key dynamic occurred between the FEDORA partners, the implementing teachers, and the substance experts. In the planning and subsequent teaching of the My City of the Future module, the FEDORA researchers functioned as initiators and coordinators of the planning, e.g. by providing both learning and research goals for the experimental module. The substance experts participated in the planning, indicating key issues about future cities, and interacted directly with the students to provide voices of experience from fields where future cities are envisioned or built. By being physically present, the experts not only functioned as sources of deep disciplinary and interdisciplinary knowledge but also as models of various expert roles in future building to combat stereotypical images of “distant changemakers”. Finally, the implementing teachers knew the students and their backgrounds, organised the practicalities of the course, and in their teaching contributed links to wider curricular content. In this manner, each of the three clusters contributed something the others could not, resulting in distinctive teaching-learning events.

Meanwhile, the advisory and policymaker expert groups met with the rest of the HOSN in intensive full or half day workshops, where the goals of the FEDORA project, the challenges and opportunities of the Finnish educational landscape, and the potential of future-oriented science pedagogies were discussed. As a key input, the overall topic of the course (future cities and climate neutrality) emerged from the initial discussion.

From the experience of building and working in the Helsinki Open Schooling Network, we recommend engaging in similar processes when resources allow. Furthermore, we recommend including, on one hand, a diverse group of experts (from principals to climate scientists, from futures thinking experts to doctoral candidates in energy system engineering), but identifying clusters in the final OSN to propose (rather than assign) clear roles. Finally, we especially recommend building such interactions around innovative teaching-learning modules that deal with the future, as the future offers a great context for participation from various roles for advisory participants, teachers, and students alike.

The Oxford Open Schooling Network

The Oxford Open Schooling Network (OOSN) was first set up through contacting various networks and connections. To inform the specific directions and focuses of the network, a questionnaire was designed at the inception stage. 14 responses were received from invited participants including teachers, researchers and museum educators.

The network also organised two online meetings to introduce FEDORA and the newly established network, and at the same time collect stakeholders' opinions on the aims of and strategies for the network. Participants in those events included scientists, school teachers and museum educators. A major aim within the OOSN is to build a common vision or goal in the broad realm of improving science education. Although the network is an initiative that emerged from FEDORA, the discussions highlighted the relative autonomy of the network to account for local and regional interests. The meetings also stressed that the aims of the group are: a) bringing together different stakeholders to generate a vision for future-oriented science education; b) exploring some solutions to the knowledge and skill gap that traditional educational organisations have not yet considered when developing students' future-oriented skills.

When preparing for the implementations, we collaborated with the science department of a secondary school on the theme and the content of the workshops. At that point the school was trying to pilot a new school-based curriculum to promote climate literacy and core skills across their year groups. Utilising the OOSN to feed into local interests, the Oxford team adapted this new curriculum and finalised the design of the workshops for the WP4 implementations in FEDORA. The materials and the workshop content were revised in the second round of implementations but essence such as climate literacy, core skills and the FEDORA missions were all retained. The workshops were held in the Natural History Museum in Oxford and were co-conducted with the museum educator to promote science learning in an informal context. In total, six implementations were delivered between June 2022 and May 2023. Each of the sessions received very positive feedback from both students and teachers. The impact of the project is being investigated through the responses to the questionnaires distributed at the workshops. In the final workshop that took place in May 2023, the science teachers were so impressed with the design of the workshop as well as students' reactions to the activities that they decided to revise the scheme of work in their school for lower secondary years. The teachers were also planning to start a new school club to promote interdisciplinarity in science learning. Another accomplishment worth mentioning, is that the team took a step further by engaging with schools and students from disadvantaged neighbourhoods. Through participating in our workshops, students from those schools were given a chance to visit Oxford (many of whom for the first time), and to engage with scientists and researchers in an informal setting. A particular emphasis in the workshops was gender inclusion and career progression. A set of resources developed as part of the OOSN workshops have been compiled with extra funding from the Impact Facilitation Award from Oxford. These resources have incorporated the components of gender and careers in the form of teacher guidelines and student worksheets. The resources are publicly and freely available on the FEDORA Project website[10].

In summary, the nodes of the network include students and teachers who participated in the workshops (both in the inception and implementation stages), researchers from the FEDORA Project and educators from the Oxford Natural History Museum.

FEDORA results: three case studies

In D4.2 and D4.3, we have presented and discussed the analysis concerning "FEDORA materials' effectiveness to develop thinking and future-scaffolding skills and to foster aware,

[10] https://www.fedora-project.eu/resources-for-inclusive-science-education-published/

responsible and proactive engagement with science" in relation to the two rounds of implementations.

Briefly summarising, the **19 implementations** present a huge level of diversity able to cover all the main themes of the project and to address a variety of research questions and issues.

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 implemented 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. As we explained above, 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.

The different research issues were addressed by analysing the data through a variety of methodologies, according to the aim of each implementation but also to the expertise of the three OSNs. The methodologies used were 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). However, quantitative studies (especially by OOSN) were conducted.

The comprehensive analysis of all the implementations is reported in D4.2 and 4.3.

According to the aim of this deliverable D4.4, in this section we report **three case studies** (whose analyses have already been conducted and presented in D4.2 and 4.3) chosen as emblematic cases to show how the research conducted within FEDORA and embedded in the three frameworks led to the formulation of design principles which informed the design of activities/modules/prototypes implemented in three specific contexts, achieving novel results and producing reflections. They are not comprehensive of all the results achieved by the project but are emblematic because they show the embodiment of principles in some open-schooling contexts.

In this chapter, each research team related to the three OSNs presents an emblematic case by writing the story in their own style highlighting the peculiarity of the context, process, and results achieved.

The following table offers an overview of the three case studies:

ID of the implementation (OSN-YEAR-ID)	Extended name of the implementation	FEDORA main pillars addressed	Type of analysis carried out
BOSN-2023-AI	Artificial Intelligence (AI) Atelier	WP1-2	Qualitative
HOSN-2023-CITY	My city of the future	WP2-3	Qualitative
OOSN-2023-MUS	Climate Change and the Future of Learning	WP1-3	Quantitative

The tree case studies will be presented in the following in order to highlight three emblematic FEDORA cases and to explore more in depth three different results related to:

- Interdisciplinarity in co-design and co-teaching (BOSN)

- [Change in futures perception (HSN)]
- [Inclusive science education (OSN)]

Interdisciplinarity in co-design and co-teaching (BOSN)

Background

The contemporary challenges (such as climate change, artificial intelligence, etc.), interdisciplinary by nature, are challenging the kind of knowledge and competences that the schools are equipping the young generation with and its current organisation in subjects. In the last few years, the European Commission has invited to rethink the school as an open ecosystem (open-schooling), in cooperation with different stakeholders, can become an agent of community well-being, as well as researchers, professionals, civils and wider society, should actively bring real-life projects into the classroom[11].

These contemporary challenges are also questioning traditional teaching methods. Studies have started to argue that co-teaching and co-planning can be change drivers to fruitfully achieve and implement educational school reforms by incorporating new curriculum content and teaching methods to develop 21st-century skills (e.g., Harkki et al., 2021; Vesikivi et al., 2019). In particular, these methodologies provide a unique context for professional development, allowing teachers to enhance their collaboration skills, bring together diverse perspectives, and enable the creation of innovative teaching approaches that may not be possible in other contexts.

The University of Bologna has carried on an interdisciplinary experience of co-teaching and co-planning within the BOSN, whose Liceo Scientifico A. Einstein was an important part.

Context

Liceo Einstein in collaboration with the University of Bologna has implemented two courses on the theme of Artificial Intelligence within the FEDORA project: a course on AI and the AI Atelier. The first one was initially designed and developed as an I SEE implementation (2016-2019), which the high school, in collaboration with the University, continues to implement within the school context. The AI atelier, an interdisciplinary activity between art and artificial intelligence, was carried out as a follow-up of the Quantum Atelier activity (see deliverables D4.2 and 4.3). The courses aim to encompass the cross-transdisciplinary character of innovation and to make research and science an open and collaborative space; to contribute to the need for new languages and narratives to enhance imagination and the ability to talk about contemporary challenges; to support young generations to build visions that empower their actions in the present.

The course on AI was organised as an extra-curricular course (*"Percorsi per le Competenze Trasversali e l'Orientamento"*) and lasted about 20 hours divided into six meetings and a final seminar. It was implemented between January and February 2023 and involved the participation of 24 fourth and fifth-grade students.

The AI Atelier followed the course on AI, it was carried out as an extracurricular activity. It lasted about 20 hours and involved 14 students.

The course on AI was organised by three mathematics and physics teachers (A, B, and C), the AI Atelier involved also a literature teacher (D) and a philosophy teacher (E). Co-design and co-teaching methodologies were adopted for the development of both the two courses. The

[11] https://cordis.europa.eu/programme/id/H2020_SwafS-01-2018-2019-2020

teachers share that, in this world where digital pervades in every dimension and the speed with which the available technologies change is very fast, there is “the need to make students aware of the digital environment in which they are immersed since their birth and which they tend to perceive as 'natural'.”

A master's student of the University of Bologna, with the supervision of two researchers, attended and closely observed the implementation of the course on AI and AI Atelier with the aim of observing (i.) how the teachers implemented co-planning and co-teaching methodologies for the development of an interdisciplinary course and (ii.) which contextual factors and relationships, both inside and outside the school, can promote the implementation of these new teaching methodologies (Molinari, 2023).

Analysis of the results

At the end of the AI Atelier, individual interviews were carried out with the five teachers (A, B, C, D, and E) who implemented co-planning and co-teaching methodologies in the course on AI and AI Atelier. The interview protocols were different according to teachers’ participation in the course on AI and AI Atelier. The interviews were audio-recorded and transcribed. For the analysis, the main sources of data are teachers’ interviews and an official document produced by them and published on the school website[12].

The interviews were analysed through a bottom-up thematic analysis to identify the main themes and sub-themes to which the teachers refer.

The protocol was organised in four areas: i. The evolution of the course on AI (Teachers A, B, C), ii. Implementation of co-planning and co-teaching in an interdisciplinary approach (Teachers A, B, C, D, E), iii. The relationship (Teachers A, B, C, D), and iv. the school context (Teachers A, B, C, D and E).

As regards the first area, two main themes were carried out: i. the need to introduce the topic of AI in schools ii. the relevance of the I SEE backbone structure of the AI module[13].

As stressed in the AI Atelier official document as well as in teachers’ interviews, it is relevant to introduce the topic of artificial intelligence in schools (i.) since today the young are digital natives: they are so immersed in the digital world shaped by ICT (Information and Communication Technologies) that they often do not realise it and, consequently, do not fully understand the benefits and the associated risks. The overarching aim, which for these teachers should be pursued by the schools, of both the course on AI and AI atelier is to make students aware of the world they live in, capable of "reading it" and develop critical thinking and competences that can help them to better grapple with contemporary challenges and the society of acceleration.

Teachers A, B, and C, who developed the course on AI, emphasise that, even if the activities and the content are updated to take the pace of the rapid technological changes and innovation, they continue to follow the I SEE model’s structure of the course (ii.) that includes: an initial overview of the topic; A technical/conceptual-epistemological part related to programming approaches; A final part dedicated to future-oriented activities.

As regards the second area, five main themes were carried out: i. the importance of an interdisciplinary approach to teaching the topic of AI ii. the benefits of implementing

[12] AI Atelier on the school website: https://www.einsteinrimini.edu.it/wp-content/uploads/2023/05/Atelier-sito.pdf

[13] The AI module developed within I SEE project is available here: https://iseeproject.eu/i-see-module-on-artificial-intelligence/

co-planning and co-teaching methodologies, iii. the necessity of "feeling" and of a relationship of trust among co-teachers, iv. phases of co-planning and co-teaching, v. challenges of the methodologies.

All the teachers stressed the importance of an interdisciplinary approach to teaching the topic of AI (i) since it does not belong to any specific discipline. The topic has been addressed from scientific, epistemological, artistic, and philosophical perspectives, and each teacher contributed according to personal expertise. (i.e., Teacher D: "T*he subject was approached from multiple perspectives, artistic, humanistic, philosophical, scientific..., then it was discussed, each person contributed from their own perspective and expertise... I felt that it was something real* [referring to the interdisciplinary experience], *there was a true exchange*."

Among the main benefits of choosing an interdisciplinary approach and its implementation through co-planning and co-teaching methodologies (ii) discussed by the teachers, one is that there is no need for a single teacher to know everything about the topic, but rather share the responsibility of teaching it with other colleagues (i.e., Teacher B: "*It was very important to know, however, that you can also rely on other people, so it's not obligatory to know everything. This reassured me quite a bit over time, so I approached this topic aware of my limitations and abilities. In the beginning, I was quite frightened because it seemed like a tough subject and one for which I needed to know something* [...] *In my case, I followed my interests, so more of a conceptual reflection, focusing on various dimensions like ethical, and social, rather than just the technical aspects...However, we divided the responsibilities*"). Another benefit concerns the students' learning that, by seeing the same topic from different perspectives, they can grasp the "*unity of knowledge*". This was stressed, in particular, by Teacher E: "*I've seen* [...] *that co-teaching is crucial for the students, who in some way approach the discipline from unusual directions and perspectives, and it help them [...] to grasp the unity of knowledge*." Furthermore, the implementation of these methodologies has also the benefit of open teachers' minds since they can "enrich" their ways of teaching in their traditional lessons (e.g., Teacher E: "*Opening one's mind to different experiences and adopting a different approach to one's discipline has personally given me a lot. I had never dealt with artificial intelligence before, and now I have started reading and delving into it, which enriches my teaching*". All the teachers emphasised the importance and necessity of "feeling" and a relationship of trust among them (iii). To work well together, for them, there is the need to have personal, professional, and friendly relationships (e.g., Teacher E: "*A genuine connection among teachers, not just in terms of friendship, but a free sharing of interests and perspectives.*"). Furthermore, to effectively collaborate it is also very important to share the same work philosophy (Teacher B: "*Certainly, based on my experience, the ability to work with individuals who share the same work philosophy and to distribute tasks in a way that promotes a sense of calmness has been essential. It allows one to engage and take risks, while also operating in a comfortable environment.*") From teachers' answers, we identified some phases that the teachers follow for the co-planning of the course (iv):

1. Exploring the topic with the aim of understanding the kind of contribution that each teacher can give;
2. Involving experts outside the school context, namely outsourcing some activities and lectures to give the possibility to students to hear different voices and approaches.
3. Involving other colleagues due to the interdisciplinary nature of the STEAM topic. All the teachers shared the importance of integrating SSH disciplines and involving the literature and art teachers. In the case of the AI Atelier teachers aimed to widen students' perspectives about AI and its implications in terms of the relationship between humans and machines.

More operationally, from the analysis, the following sub-themes emerged as pivotal in the organisation of the course and collaboration among the involved colleagues:

- Individual preparation with reading of texts and articles on the topic.
- Support and collaboration among teachers: All the teachers confirmed that they worked well together and supported each other. This includes the exchange of materials as well as the sharing of information based on each person's specific expertise. The teachers also highlight the psychological and emotional support they provided in moments of demoralisation, which may be related to the challenges of the work.
- Division of roles: The teachers state that they organised themselves based on their skills, preferences, and interests. However, they emphasise the need for each person to have a clear role, both in terms of organisation and in terms of content.
- Balance among teachers: No one should be underestimated, and each person should have an equally important and relevant role compared to others.

As regards the co-teaching, from the analysis we have individuated the following sub-themes:

- Collaboration, balance, and respect are some key values that characterise co-teaching and the space of "co-teaching", intended as the atmosphere that is established in the classroom.
- Complicity among the involved teachers. During the activities, there was a meaningful level of participation, collaboration, and complicity among the teachers, especially between Teachers A, B, and C, who have been collaborating together for many years. When one teacher gave a lesson on the agreed-upon topic, the colleagues were attentive and ready to intervene with probing questions to the students or making connections.

In general, teachers argued that the implementation of the co-planning and co-teaching methodologies is challenging (v.). Difficulties are highlighted, especially due to the limited time and the professional commitments of the teachers, as well as the students' own commitments. Another shared challenge concerns the lack of time (e.g. *Teacher C:" The most difficult thing is to ask for extra time beyond the work you already do because if you don't consider that, you won't accomplish anything*.")

As regards the third area (relationships), the teachers indicated three main relationships as important for the development of the course on AI and AI atelier: i. relationship with the University of Bologna ii. relationship and collaboration with different high schools iii. relationships with the school management.
The activities that the teachers carried out were born from the collaboration between the research group in physics education of the University of Bologna and the Liceo Einstein (i.). The teachers stressed that the university provides guidelines, values, and tools to develop the course and gradually the school has become more autonomous and capable of organising, managing, and refining the course on its own. Nevertheless, the teachers highlighted the importance of collaborating with the University in terms of research and the involvement of experts for seminars and masterclasses. For the teachers, the experts' interventions are important for students by offering them a significant opportunity to connect with the world of research.
Teacher B stressed that different schools are working on AI themes and how it is increasingly important to establish new collaborations (ii.). A national network of high schools is now

being created with the aim of bringing AI into schools and providing teachers' training courses.

All the teachers highlighted that the school management has supported the initiative of the course on AI and AI atelier (iii.). However, Teacher B stressed that it is necessary for the school management to support more some initiatives than others, providing clear direction on which courses to offer, and facilitating meetings among teachers. This aspect could help to not have an excessive number of courses and therefore diminish the difficulties of students who are already burdened with numerous commitments. (e.g., teacher B: "W*e have to deal with the excessive number of projects that bombard the school; my idea would be 'less is more,' we need to make a selection.*"; Teacher D: "*We feel supported [...] in my opinion, what is missing is the opportunity for people to meet, because it's important for the school to convey that it wants to take a clear direction* [...]. *The school should actively promote, in a practical manner, the work of even just a group of people.*"). Finally, teachers stressed also the importance of having clear roles to nurture the relationships between the schools and the other stakeholders. In particular, two are the roles that the teachers indicated: the importance of the coordinator between teachers and the University (Teacher A) and the coordinator between the teachers and the school management as well as between the school and the teachers of other schools of the national networks (Teacher B).

As regards the last area (the school context of implementation), the teachers stressed that there are some constraints due to the school context (i.) and proposed a new implementation opportunity that can enhance the importance of the courses (ii.).

All the teachers highlighted, during the interviews, the importance of including AI as a curricular topic. Nevertheless, the placement of these courses within the school reality encounters constraints (i.) The teachers identify constraints related to the school as an institution with its regulations, legislative aspects, and rigidity. Another kind of constraint identified is related to school management. There are some principals who are more innovative and open to changes, while others are more conservative. A few teachers argued that the management could provide more 'active' support, not limited to just giving approval for these courses but creating conditions for their implementation by providing the right spaces and time. Finally, the teachers discussed another kind of constraint related to the resistance to change of more traditional teachers and the difficulties of involving them in promoting new initiatives.

All five teachers proposed to place the course on artificial intelligence within the curricular schedule, as hours of civic education (33 hours per year that are mandatory for all the high school classes). This proposal could solve some of the concerns and issues identified by the teachers as all the students should have the possibility to be introduced and attend these kinds of courses. Furthermore, the implementation of the course during these mandatory hours would make their management consistent. Currently, as reported in the interviews, the teachers often use these hours to delve into topics related to their own discipline. The interviewed teachers argued the importance of dedicating these civic education hours to contemporary relevant topics, such as artificial intelligence (AI), that can be approached in an interdisciplinary manner. Another advantage would be the diminishing of the extracurricular commitments load both for students and teachers. Finally, three teachers also emphasised the need for greater involvement of the school administration trying to reach an agreement among the class and school councils to include these topics in the school timetable.

Change in futures perception (HSN)

Background

The global sustainability crises and the accelerating societal and technological development demand science education to address students' concerns and uncertainty towards the future. A lack of stable future horizons can lead young people to regard the future with hopelessness, to take directionless actions and to exhibit inabilities to project themselves into the future. Meanwhile, the United Nations' Agenda 2030 programme calls for societal transformations that cannot be achieved without transgenerational thinking, responsibility and transformative agency of the young.

The FEDORA Framework to Futurize Science Education[14] addresses these concerns by suggesting how science education can provide students with tools for connecting with, and finding agency within, their personal and global futures. Based on the results of six FEDORA part-studies on students' perceptions and European curricula, the framework proposes a set of 14 research-based recommendations to *future-orient* science education. The recommendations address problematic issues and limitations in students' futures thinking, connect futures thinking skills to scientific and technological skills and knowledge, and address related aspects of educational design and school culture.

The FEDORA module developed in Helsinki implemented these recommendations in an upper secondary school course that is described and analysed in the following.

Context – course description

The FEDORA-module, developed by the University of Helsinki in collaboration with the Helsinki School of Natural Sciences, engaged students in creating a sustainable future for the city of Helsinki, Finland. The module consisted of an experimental science course, titled "My city of the future", and was held in 2022 and 2023. Both courses consisted of 6-7 lessons over the course of 2 months. The courses began with an introduction to futures thinking: how it often fails to predict the future, yet one can improve and systematise one's visions, for instance, by distinguishing between thinking about possible, probable, and desirable futures.

Over the course, students worked on their visions for Helsinki in the year 2050. In the first course implementation, they wrote textual visions, in the second they created posters, both in groups. The projects were continually challenged by the teachers as well as three invited consulting experts (smart city anthropology, values in futures thinking, energy, and sustainability transitions). The students also built timelines between today and their vision, mapping central actions to take to reach their desired future, paying special attention to systemic perspectives and the role of technology, science, and built environments in creating sustainability (e.g. energy production) and shaping the city of the future (e.g. new technologies). Pedagogical futures education methods, such as visioning and backcasting were used with aims of promoting future-orientedness, process thinking, understanding of causalities, and (un)certainties.

Then, 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 this they met with one of the authors of the CNH Action Plan to discuss the rationale for the environmental policies of the city of Helsinki.

[14] Available at https://www.fedora-project.eu/deliverables/

During these activities, students compared their own thinking with official policies and contrasted the actions they wished to see taken with those currently planned or executed. Finally, guided by the teachers of the course, the students collected their visions of Helsinki in 2050 into a small pamphlet (2022) or a poster session (2023). The course ended with a discussion panel between the students, the head or a member of the city of Helsinki's Climate Team, and other students from the school in the audience. At the end of the panel, 2022 the finalised pamphlet was handed over to the city, whereas the 2023 poster sessions was structured as a discussion where students "pitched" their desirable future scenarios to the city. The intention was to provide a clear point of connection between the current city plans (for 2035) and students' visions (for 2050) while giving the students an authentic, emancipating experience of participating in discourse on the future of the shared city.

Analysis and results – Changes in futures perceptions

Over the course, multiple datasets were collected to capture students' futures thinking in "real time" in the course structure as well as in post-course reflection. Namely, drafts of student groups' future visions were periodically collected (to capture the application of learned skills and other effects of learning activities), groups were interviewed in depth after the module (2022), and students periodically reported on their learning experience by writing "post-lesson reflections" (2023). In addition, a SenseMaker survey was used in 2022 to triangulate changes in students' futures thinking. These datasets were then analysed as a whole, building on the notion that different recommendations for future-oriented learning are relevant in different contexts.

From the dataset, some key observations emerged to support the construction of the FEDORA recommendations. Here, we provide three examples of these insights. Namely: 1) there are specific points of connection between scientific domains and futures thinking that are relevant to future-oriented science learning (relevant for FR3 recommendations R-II, R-VI R-VII, R-XI); 2) future-oriented science learning can constructively activate critical thinking towards simplistic science attitudes (relevant for R-VI, R-VIII, R-IX, R-XIII), and 3) activities addressing perceptions of agency for the future have potential to bring agency closer to students' identities (relevant for R-I, R-V, R-VIII, R-IX).

In the following, we provide an illuminating example of all these phenomena, before giving more general remarks on our findings.

The first observation (the specific points of connection between science learning and futures learning) is evident in the following excerpt from this excerpt from one student's post-lesson reflection:

> "I really got caught up in thinking about artificial photosynthesis... Not so much as a real alternative, or a sensible one, but as a thought and question: 'would it even be possible?'"

Given the rate of development in science and technology, this student's question is not misguided or scientifically illiterate. Indeed, as a *science learning question*, evaluating what is scientifically feasible and what is not is at the core of scientific literacy! However, speculative, deeply technical issues such as this can emerge from future-oriented learning, posing challenges for supporting the student's sensemaking. Meanwhile, as a *futures learning question*, what is notable about this student verbalising their speculative futures thinking: this is not an immediately central question to their vision of a sustainable future (for unnamed reasons). In fact, the student seems to be making a qualitative difference between plausible avenues of scientific advancement, and a type of scientific curiosity. To understand future-oriented science learning, these interfaces are highly relevant.

The second observation (constructively problematising simplistic notions of science and the future) is spelled out in the following excerpt from one group's future vision (2022 course):

> "People used to think technology would fix everything: climate change, the environmental crisis, political unrest, crime, marginalisation, drug use, etc. Countless hours were spent developing technology, taking up a lot of resources and work hours, but new technology would not just magically fix things."

While this passage is somewhat uncompromising (it paints the picture of technological development as mostly futile), it also constructively criticises simplistic narratives of technological fix to complex problems. Here we may identify a unique effect of the module's activities (such as addressing the extremely complex case of a city, and constantly introducing further complexity to questions addressed): the criticism is aimed at a simplistic narrative or discourse, not any specific area of technology. This can be very constructive as a pedagogical process, because it is highly abstract. As another example, consider the following extract from one student's post-lesson reflection:

> Change should be sought primarily from the current world: reducing consumption and moving on to more efficient alternatives. As science and technology advance, they may alleviate these problems. We just should not count solely on them.

As a final example, the activities of the module seem to have had an effect on students' perceptions on agency for the future. These were manifold, but overall they indicate complexifying conceptions about "who makes" the future:

> On the course I realised a lot about politics, that it's more important for the future than technology, because without good politics technology is of no help.

> I now feel a bit more passionate about the future, at least in the sense that I don't just think about it, but I want to also change it.

As students explored pathways of change, they repeatedly indicated that futures thinking can allow one to notice shortcomings and achieve positions of influence in order to change the state of matters, especially if the process can begin at a young age. One student summarised their experiences as "*I think the most important takeaway from this was that we can actually do things for the future.*"

Overall, concrete, self-reflected changes in students' futures perceptions were directly recognizable through their interviews held after the first implementation of the futures education course. When asked about the impacts and meanings of the course they had recently undergone, students spoke of increased perceptions of agency and improved understandings of decision-making processes. They spoke of improved concretization of their own future images and perceptions, which in turn improved their beliefs in the powers of change and agency. One student explored their own futures anxiety related to the state of the climate and concluded that the course was able to improve her strongly negatively tainted views of the future world. A sense of relief and improved well-being were central to students' answers, especially if they had previously experienced strong futures anxiety.

Through the implementation of a futures education course, students were able to perceive the future more holistically. Students developed deeper conceptions of the complexity of the future through the lens of the city. They gained understanding of the roles of agency and perceived how their actions can and will impact the future. By further looking into the themes and topics discussed within the individual groups' visions, the study found that even in a small sample size study, student groups wrote visions that differed entirely from others.

Emphasising the concept of futures as undefined, pluralistic scenarios, each group wrote a personal future vision whilst attending the same futures education course as the other groups.

The results of the analysis show that students' understandings of the complex systems and their interrelatedness developed substantially during the course, showing positive predictions for the success of similar futures education courses. Overall, the resulted development of students' future visions during the futures education course provided strong insights into the implications of such futures education courses: the development of systems thinking and agency perceptions, among others, sheds light onto the progressive benefits of allowing, encouraging, and challenging students to work to build and solve a future in which they would wish to live. In merely a short-term course, students' understanding of how future perceptions can change from abstract ideologies to concrete plans.

As one takeaway, futures thinking in schools not only allows students to understand the possible futures of the world, but also evaluate their own thinking skills and models. Development of futures perception through futures education can promote an understanding of an individual's role within an ever more complex world and foster the perception of their ability to impact the future. By understanding the complex roles of society, nature, science, and technology, students began to concretize their hopeful futures into actions in aims of creating a more environmentally and socially sustainable future.

Inclusive science education (OSN)

Background

The inclusive science education theme in the implementation design of OOSN has taken forward the recommendations from WP1 and WP3. Firstly, we acknowledge the importance of "connecting formal and informal education", "context of co-teaching" and "co-construction of learning spaces". The OOSN implementation adopted all these three elements from WP1: a) we connected the school curriculum (formal education) on climate literacy with museum education (informal education) on biodiversity; b) we co-taught the implementations with non-scientists and museum educators to encourage multi-disciplinary perspectives; c) the implementation design focused on co-constructing a learning space with participants by strengthening students' voice and future thinking. Giving voice to young people is at the heart of the OOSN implementation. Inclusion was thus effectively framed and promoted by incorporating recommendations from WP3 on "the role of agency in students' learning" to address the "lack of imagination and alternatives in students' future narratives". Right from the beginning, boosting young people's agency in their imagination of the future carried a strong weight in the OOSN implementation goals. Activities and materials were specially designed to prompt students to give different opinions (i.e. making their voice heard, however different they might be) which are based on action-oriented thinking (i.e. what they have done and can do to impact the future, at both personal and collective levels). The theme of youth empowerment was sustained throughout the design and the execution of the OOSN implementation.

Guided by the FEDORA manifesto and recommendations from WP1 and WP3 especially on creating engaging narratives, inclusion in OOSN was manifested in various undertakings – widening participation, designing the implementations and learning resources, and youth empowerment. This overarching goal was thoughtfully addressed and embedded in all stages of the network activities. Our aim is to engage with young people and include their voice in creating a common and focused narrative about the future of science education. This section will illustrate how inclusion was embedded and fostered through different features of the work in OOSN.

1. ***Widening participation in informal learning contexts***

Inclusion was bolstered through creating chances for students to learn and reflect in informal environment outside a school context. Oxford is a unique place, thus the network and collaboration we sought needed to utilise the opportunities and affordances of the university, while also accounting for the demographics in the region. The Natural History Museum in Oxford is one of the many establishments within the complex university system. It is home to approximately seven million objects and has welcomed 40,000 student visits. One of the museum's visions is to educate the general public about nature and biodiversity. Utilising this valuable function within the university, all the implementation workshops in the OOSN took place on-site in the museum, in which students had a guided tour around the Victorian neo-Gothic architecture and some hands-on experience with the exhibits. Creating these learning experiences in an informal environment is to encourage student participation and create personal connections with the workshop objectives (climate change and empowering personal responsibilities); at the same time making science learning inclusive. Learning in out-of-school context and directly interacting with museum objects were particularly motivating to students with special learning needs. The Public Engagement team of the museum co-ran all the workshops with the FEDORA team in Oxford.

2. ***Design of the workshop and learning resources***

Inclusion is a significant pedagogical element running through the design and delivery of the workshops. Firstly, the workshop was designed to cater for students from a mixed-ability range or any subject background (participants were not necessarily taking science for their A-levels). We intended to make access as inclusive as possible. Teachers were reminded that our workshops did not particularly target students with intellectual prowess, a common interpretation held by schools when organising visits to Oxford. Secondly, the workshop made use of multimodal (text, visual, audio, tactile and mobile) and multimedia materials (videos, paintings, photos and museum objects) to cater for a wide range of individual needs. Thirdly, apart from teaching materials, inclusion was also discussed as a main theme through a variety of the activities. For example, students explored equity issues by discussing how women or people in poverty are impacted by climate change more harshly than other populations. Activities were organised in different formats – individual reflections, group work and presentations. Inclusive thinking also requires students to adopt different perspectives when imagining the future. One activity in the learning resources is setting up a "Youth Advisory Board". Students imagine how "green jobs" help combat climate change (for example, climate scientists or solar panel installers, or roles taken by women). The activity guides students to be more imaginative and gender-sensitive when giving suggestions. The key aim is to inspire students to think about how professional roles, including those taken by women, can help promote climate justice and gender inclusion.

3. ***Impacting young people's agency and their perceptions of climate change and school***

Inclusion was also manifested in the impacts of the workshops on youth agency. The workshop activities and learning resources strongly encouraged participants to a) shape their own views; b) share their voices so that feedback can be collected for improving science education for the younger generation; c) reflect on how personal actions can influence climate change, its consequences and the future more broadly. These overarching aims were achieved through three pedagogical strategies. First, in each workshop students were explained how their participation would play a key role in shaping the future of science education. The discussion of "future" was also linked to students' own future so that a sense of personal ownership and connectedness was created (encouraging "diversity responsiveness" recommended by WP3). Second, students, whether individually or in groups, discussed how personal decision-making impacted local, national and global issues, both present and in the future. Third, students filled in pre- and post-workshop questionnaires to provide their views on climate change and how learning organisations, including their school, prepare them for the future. The questionnaires provided data for six variables for measuring the impacts of our workshops. The following sections report results from three variables as our positive impacts on inclusion.

4. *Results from students' participation in the OOSN*

This section provides part of the results from the second round of implementations in the OOSN. We organised a series of three workshops between December 2022 and May 2023. 40 students from three secondary schools in England took part. All students were at Year 12 (aged 16-17) at the time of participation.

4.1 Engagement with climate change issues

Before the workshop, students were asked to indicate how often they had engaged in activities related to climate change in the then academic year. Despite their interest in this topic, science or geography in general, surprisingly the majority of students said they had only "occasionally" taken part in this kind of activities (median = 2; mode = 2).

4.2 Environmental agency

This variable was measured by nine question items, and six of which had recorded statistical differences before and after students' participation in the workshop. These results suggested the workshops have boosted youth agency.

4.2.1 Looking after the global environment is important to me

Statistical analyses confirmed that students' perception of this statement was significantly stronger after our intervention (Mdn = 5, n = 38) compared to before (Mdn = 4, n = 40); p = .011.

4.2.2 I can identify some consequences of climate change

Students' perception of this statement was significantly stronger after our intervention (Mdn = 5, n = 38) compared to before (Mdn = 4, n = 40); p = .008. The workshops have increased students' confidence in identifying consequences of climate change.

4.2.3 It is important for me to take some actions to limit my impact on global warming

Students indicated higher importance of taking actions to limit their impact on climate change after the workshops (Mdn = 5, n = 38) compared to before (Mdn = 4, n = 40); p = .011.

4.2.4 I can do something about climate change

Students felt more able to do something about climate change after our workshops (*Mdn* = 4, *n* = 38) compared to before (*Mdn* = 4, *n* = 40); *p* = .028.

4.2.5 I often reduce the energy I use at home (e.g. by turning off the lights when leaving a room) to protect the environment

Students were more aware of reducing their energy use after the workshops (*Mdn* = 3, *n* = 38) compared to before (*Mdn* = 3, *n* = 40); *p* = .046.

4.2.6 I often choose certain products for ethical or environmental reasons, even if they are a bit more expensive

Students felt more willing to choose products for environmental reasons after our intervention (*Mdn* = 4, *n* = 38) compared to before (*Mdn* = 4, *n* = 40); *p* = .018.

In addition to the quantitative results, we are presenting some students' reflections after taking part in the session to evident their enhanced agency about the future -

> [ZS27] *With us being later in our teen years and everything is down to our responsibility to be able to not only act in our own ways to improve, but to also educate other people. I feel programmes such as this has definitely helped educate a good number of people. I definitely feel like I came out of it learning a lot more and I definitely feel like changes will probably be made to what I do as a result of it.*

> [KV03] *I feel like people need to be given more power because we're the ones that are likely living through this. We need that voice. We need the power to change the world for the better. And I feel like we're not being given nearly enough for that power.*

4.3 Perceived future literacy

This variable was measured by four question items, all of which resulted in statistical significance (*p*<.05). These results supported the impact of our workshops on increasing students' perceived future literacy.

4.3.1 I can imagine some negative scenarios as a result of climate change

Students felt more able to envision some negative scenarios of climate change after participating in our workshops (Mdn = 5, n = 38) compared to before (Mdn = 5, n = 40).

4.3.2 I can imagine some positive scenarios as a result of actions against climate change

Students felt more able to envision some positive scenarios of climate change after participating in our workshops (Mdn = 4, n = 38) compared to before (Mdn = 4, n = 40).

4.3.3 I can identify some steps needed to achieve a sustainable future

Students felt more able to identify steps for achieving a sustainable future after the workshop (Mdn = 5, n = 38).

4.3.4 I can identify some steps that, I, personally, can take to achieve a sustainable future

Participants felt more able to identify some personal steps that they could take for a sustainable future (Mdn = 4, n = 38).

Below are students' post-intervention reflections to illustrate the positive changes on their perceived future literacy and thinking:

> [CH28] *I feel like this session has made me want to do something in the future because my understanding on this is going strong through this workshop. From looking at current affairs and having more of a clear sign of the severity of the situation with climate change, I feel, I could do things to help out.*
>
> [FP06] *Quite empowering because I've been taking more of a stance recently in trying to promote these benefits to others, like trying to promote the positive future scenarios, you know, heckling my family at home to be mindful of energy usage.*

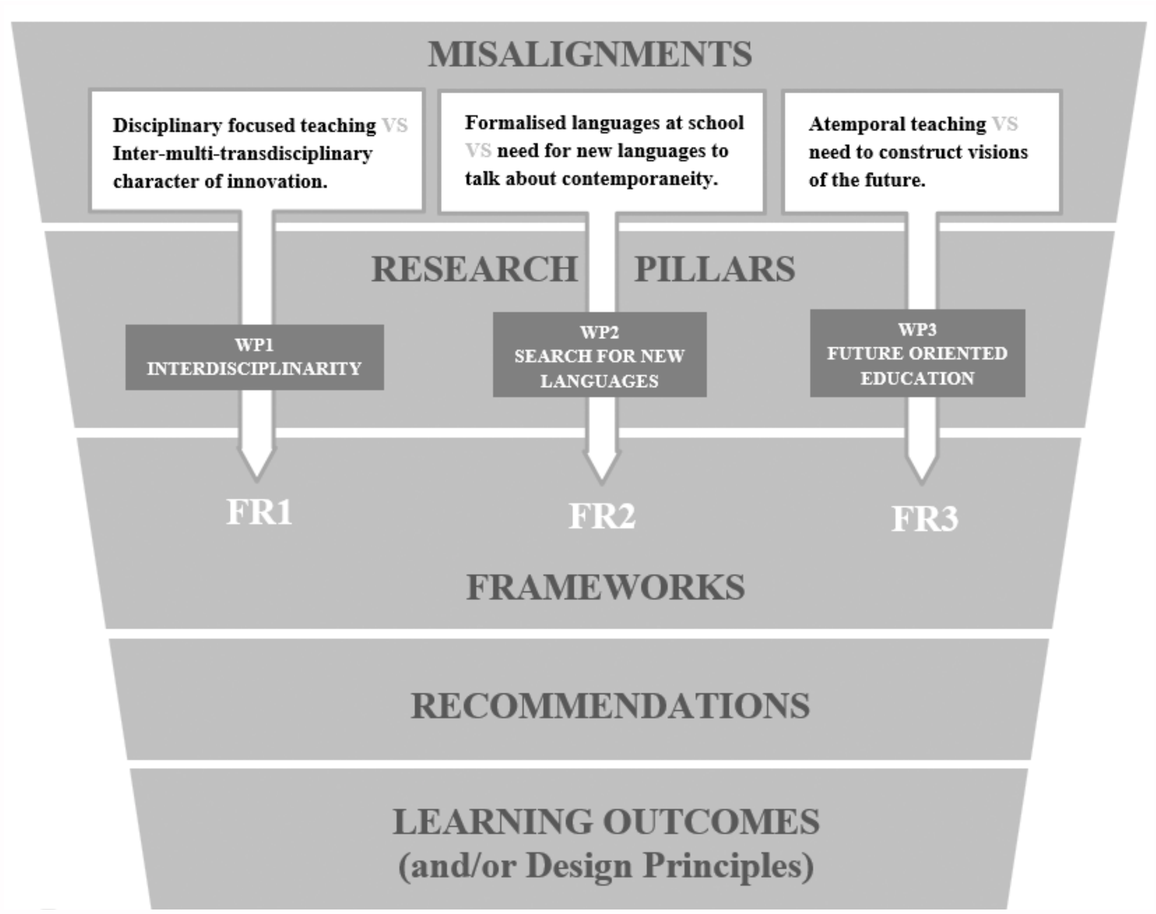
5. Summary

In the OOSN inclusion was understood and manifested in various aspects. Inclusion was achieved in terms of process (context, interaction and engagement) and outcomes (production of learning resources and impacts on students and teachers). Overall, we have generated –

- access to and opportunities for science learning in informal environments;
- teaching and learning resources to be adopted in the classroom or other out-of-school contexts, with specific focuses on gender awareness and careers;
- impacts on youth empowerment showing some statistically significant changes on students' sense of environmental agency and perceptions about the future related to climate change.

Conclusions

In this deliverable we presented the FEDORA "**Model for science education**" that resulted from a back-and-forth-dynamic among WP4 and WP1-2-3. The model was progressively fleshed out from the two rounds of implementation carried out within the three open schooling networks as well as the progressive findings coming from WP1-2-3 that fed into WP4. The analysis of the three misalignments (the research pillars) produced the three FEDORA frameworks FR1-2-3, whose highlights and recommendations oriented the materials design of future-oriented, inter-multi-trans-disciplinary and multi-languages materials. Such recommendations have been turned into learning outcomes in the open-schooling and co-teaching practices. The results from the first round of implementations and some ongoing results from the second round fed back into the frameworks. The structure of these layers is represented in the following figure. Emblematic case studies which illustrates how the model appeared in practice are also reported in this deliverable.



The implementations of FEDORA recommendations in school contexts represented a challenge for the governance of the schools, teachers and students. It implied opening and questioning relational and epistemic elements that have historically characterised the educational systems and the professional identity of the teachers. However, dealing with this challenge has activated interesting dynamics that appear promising to regenerate the ecosystems of science learning in formal and informal contexts at different levels: contents of science teaching, priorities in the goals and outcomes of science teaching, relations among the teachers, institutional organisation.

Future implementations will allow us to unpack and analyse in more detail the quality and the entity of the transformative potential of the FEDORA model.

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