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Pathways for a future-oriented science education

A handbook from the FEDORA project

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FEDORA - Future-oriented Science EDucation to enhance Responsibility and engagement in the society of Acceleration and uncertainty
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Welcome to the FEDORA handbook!

During these last three years, we have been working collaboratively and diving deep to find answers to our burning questions about science education.

How can we help the students to find in education the resources needed to construct empowering visions of their future and develop competencies to navigate a complex, fragile and fast-changing society?
How can we make science education more inter-multi-trans-disciplinary?
What do we need to create new languages tuned with the current times?
What do students and their educational communities feel and think about the future? And how can we contribute, as a project and as a group of committed professionals, to the expansive reach of Open Schooling, as a model of putting in practice "new ways" to regenerate education?

The FEDORA project brought together experts and stakeholders from different fields to explore new approaches and tools for science education that would better equip learners for future challenges.
Through its research, FEDORA sought to foster a culture of innovation and creativity in science education while promoting sustainability, diversity and inclusion.

This handbook is a comprehensive and quick guide to the FEDORA project's findings, insights, and recommendations for science educators, policymakers, and anyone interested in science education as a driver for sustainable futures. It presents a range of perspectives through our studies, a set of recommendations and frameworks, inviting you, dear reader, to apply them in various educational contexts.
They are conceived as conceptual tools that can help educators to imagine and design future-oriented, engaging, relevant, and meaningful science learning experiences for learners of all ages and backgrounds.

Whether you are a teacher, a researcher, a policymaker, or simply interested in science education, we hope you find the FEDORA handbook a valuable resource that can help you to think differently about science education and to explore new possibilities for transforming the way we learn, teach, and engage with science and society.

We wanted to stimulate a regeneration of the science education ecosystem by searching for new languages and investigating interdisciplinary and future thinking.
We will be happy to hear from you if we made it after reading and, hopefully, using this handbook.

Olivia Levrini,
FEDORA Project Coordinator

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1. Crossing boundaries for interdisciplinarity

Educational systems, with their tradition of vertical and hyper-specialized organization in disciplines, are challenged by the need to equip the young with competencies to deal with inter-multi-transdisciplinary issues. The guiding questions addressed 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, four-part studies were conducted: a literature review, interviews, interdisciplinary study groups and surveys aiming to identify the limits and advantages of disciplinary knowledge organization and the boundaries or barriers that pose to the advantages of inter-/multi-/trans-disciplinarity in science education.

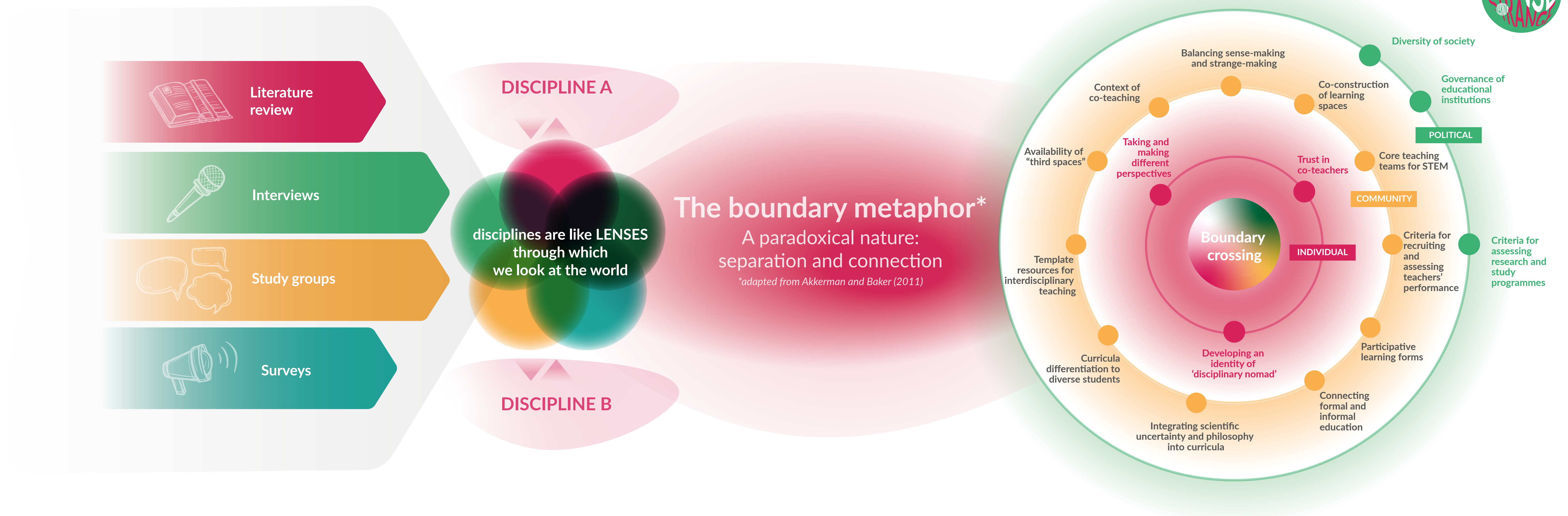
Overview of the 4 Part studies
Research findings from Finland, Italy, the Netherlands, Lithuania, the United Kingdom.

Part study 1	Part study 2	Part study 3	Part study 4
Literature review, N*=1469 n**=378 entries	Cross-cultural interviews, n=30, research performing and funding organisations, schools, industry representatives	Interdisciplinary study groups, n=2	Cross-cultural survey, n=346 high school and university students; n=42 experts

Throughout the studies, we used the metaphor of the boundary (Akkerman & Bakker, 2011) to model interdisciplinarity and its "paradoxical" nature: boundary both separates and connects. Analogously, interdisciplinarity blurs and redefines disciplinary identities and requires managing the equilibrium between "sense-making skills" - systems, critical and analytical thinking- and "strange-making skills" - creative, imaginative and anticipatory thinking. The metaphor of the barrier that we used in interpreting the results connotes a separating obstacle; differently from the boundary, barriers do not have a characteristic of connectivity and cannot be easily crossed and demand systemic changes.

N*= Total No. of entries",
n**= Selected No. of entries for analysis

On boundary crossing in interdisciplinarity



The outcomes were translated into a visualisation that integrates the five main issues that appeared as boundaries or/and barriers in formal educational contexts:

1) Divergence between *de jure* and *de facto* in educational policies and practices,
2) Extensive demands from teachers,
3) Disciplinary isolation and lack of interdisciplinary languages,
4) Graduates unprepared for life
5) Social insensitivity.

Issue 1 stems from **inconsistencies between national regulations and institutional practices,** obstructing interdisciplinarity, institutional competitiveness and social impact. They are most perceived through the arrangements at the political level, such as governance mechanisms in educational institutions and national criteria for research evaluation and funding, as well as accreditation of quality assessment of study programmes.

These discrepancies account for at least three subsequent issues at the community or institutional level. Issue 2 relates **to excessive workload and demands from teachers** and researchers. Moving towards interdisciplinarity threatens teachers' authority and self-confidence and demands extra time in connecting different disciplines. Disciplinary isolation through departments at research performing and research funding organisations and lack of interdisciplinary languages to talk across different perspectives in all educational institutions, as encoded in issue 3, creates a 'silo' effect. It constructs social, cultural, and institutional barriers as well as cognitive and epistemological boundaries to interdisciplinarity.

A closed culture of disciplinary communities further strengthens individual and community identities through **symbolic languages, representations and communication practices**. As a result, sticking to the closed culture of disciplines erects a barrier to innovative teaching (and development). Ultimately, this leads to issue 4: **graduates unprepared for working life and beyond it**. A disciplinary approach to knowledge organization is seen as erecting systematic barriers to developing transferable skills needed by the labour market and practical life, e.g. applying conceptual knowledge to practical problem-solving, self-confidence and efficacy, existential skills, teamworking, life-long learning skills, futures thinking skills etc. Current education is perceived as failing to develop these skills, and lack of cooperation between experts in STEM and social sciences is seen as a barrier to innovation development. Teaching methods applied in a disciplinary approach seem to fail to produce discussion and decision-making skills needed for teamwork.

Finally, issue 5 brings focus on the interrelation between ongoing changes at the societal level, such as **diversity of society** and efforts to address them at a community level. Rote learning, standardized tests to monitor students' progress, and academic achievement-driven culture are criticized for failing to respond to the growing diversity. The socioeconomic background of students' families affects the choice of high school. Intersectionality of students' race, ethnicity, gender, disability and other social categories decreases the chances of socially excluded or underrepresented groups to pursue education in science. The research findings indicate that some disciplines may be more gender-biased than others, e.g. social sciences are perceived as more responsive to diversity as they can include different topics, such as gender equality, into their curricula. The multicultural experience of teachers or researchers tends to make them more sensitive to the diversity of students in the classroom.

FRAMEWORK FOR ALIGNING SCIENCE TEACHING/LEARNING IN FORMAL CONTEXTS WITH THE MODUS OPERANDI OF RESEARCH & INNOVATION

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ISSUES WHEN PROMOTING INTERDISCIPLINARITY	WAYS TO CROSS THE BOUNDARIES AND/OR DECONSTRUCT BARRIERS TO INTERDISCIPLINARITY
Divergence between *de jure* and *de facto*	• Reengineering governance of educational institutions • Changing criteria for evaluating research and study programmes quality at national level • Acknowledging professional identity of teachers as co-contructors/co-facilitators of discipline-wise respectful learning spaces • Changing criteria for teachers' recruitment and performance assessment • Supporting creation of and acknowledging a context for co-teaching
Demands from teachers	• Designing the core teaching team for STEM curricula • Developing templates for interdisciplinary teaching resources • Accepting the notion that one cannot be expert in every science field and trusting co-teachers
Disciplinary isolation and lack of interdisciplinary language	• Changing the attitude and becoming a "disciplinary nomad" • Creating "third spaces" to learn taking and making different perspectives • Integrating sense making with "strange making" skills
Graduates unprepared for life	• Fostering the connection between formal and informal education • Integrating scientific uncertainty and philosophy into curricula to develop interdisciplinary competences • Fostering interdisciplinarity as a way to innovate and address complex problems • Institutionalising interdisciplinarity to promote participative learning forms
Social insensitivity	• Capitalising on the advantages of interdisciplinarity to offer curriculum differentiation for diversity (gender, cultural and socio-economic background, personal motivation) of students

Recommendations

- **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, 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 have 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 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 coping strategy of a "**disciplinary nomad**" may facilitate overcoming cognitive and epistemological barriers and enacting interdisciplinarity. To enable boundary crossing at the individual (identity) level, institutions should facilitate the development of **a common interdisciplinary language.** Focus 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's 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 organized 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.

These recommendations will strengthen science education and equip young people with interdisciplinary thinking and future-scaffolding skills.

For more details, see the full Interdisciplinarity in Science Education Framework here:
https://www.fedora-project.eu/deliverables/

2. Exploring new languages

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.

How to create these innovative ways to communicate, foster and imagine was one of FEDORA's objectives. The interpretation of Hartmut Rosa and his society of acceleration was a guiding metaphor, and based on this, ambiguity, complexity and uncertainty are permanent states and perceptions 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.

Led by formicablu, a benchmark study was the starting point enriched by internal sessions and followed by two creative workshops that gathered experts from different disciplines.
A new language is a combination of symbols - visual, written, spoken, enacted - that work as a means of transport for communicating a message to a social group that will receive it, understand it or be stimulated by it. When combined with interdisciplinarity, it supports "to describe it and talk about it" and "to communicate on different theme areas". In contrast, when combined with the future, it supports " the conditions to find words that build new realities", to find new ways to communicate or build the future and "new practices to imagine the future".

Learning a new language - or creating it- is about acquiring tools that help us understand the elusive parts of ourselves and our environments (natural and social mechanisms of our societies). In future thinking, it becomes the medium that enables us to cross the doors for radical imagination. Acknowledging that it is not only our current culture, which is highly based on visual representations, but that they constitute the bedrock for common languages, visual representations are key for helping design paths that envision futures that mingle sciences, arts and technologies.

In line with FEDORA's core metaphors, languages are tools for crossing boundaries and inhabiting these frontier zones.

The following are the languages proposed:

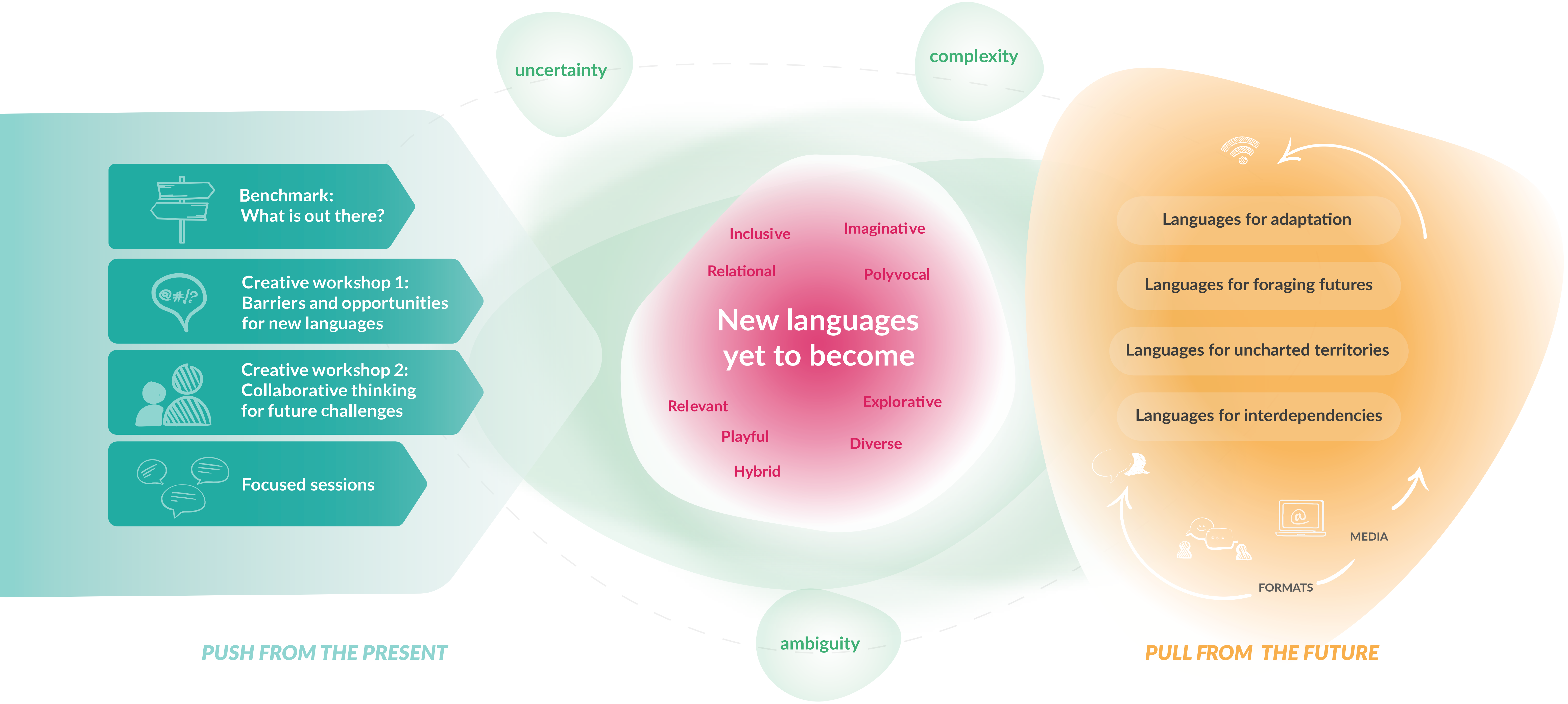
- Languages for adaptation: they relate to evolution,
- Languages for foraging futures: they relate to time,
- Languages for uncharted territories: they relate to space,
- Languages for interdependencies: they relate to interactions.

The framework explains the sources and flows underpinning the co-creation of new languages.

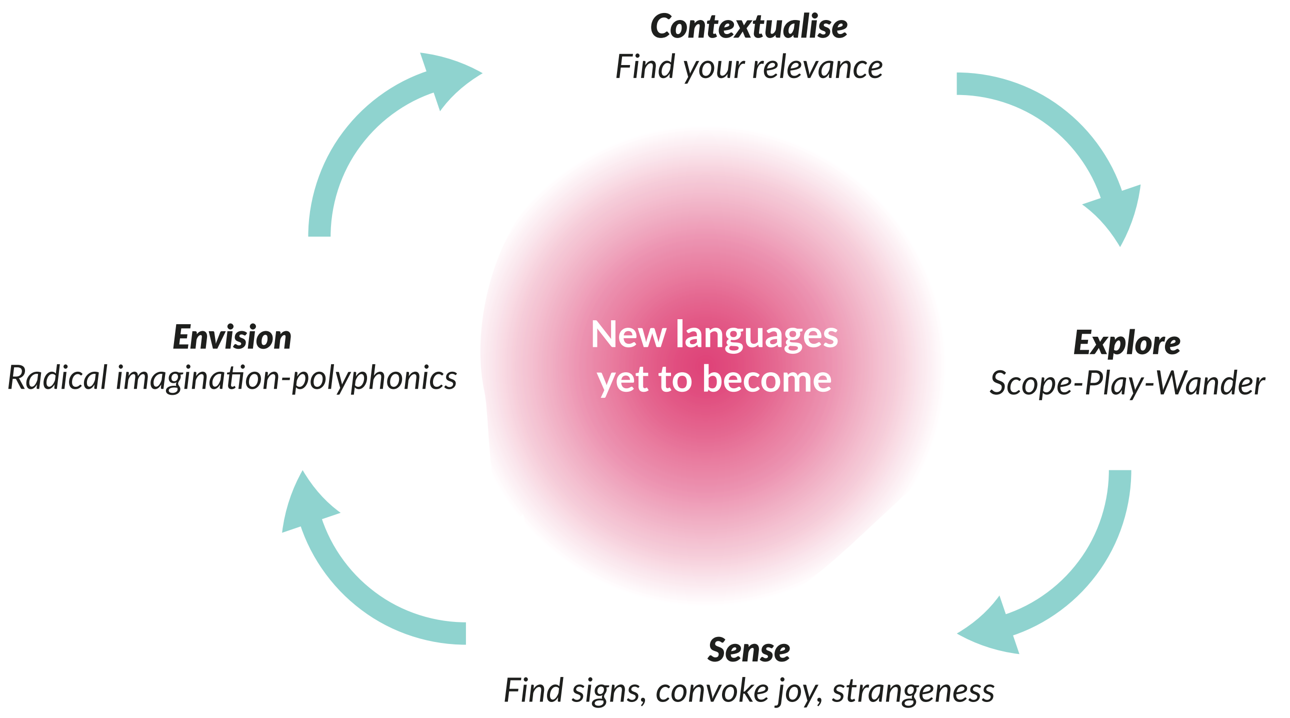
A linear trajectory transitions into a multidirectional one. It avoids a prescriptive recipe. Therefore border lines are open and organic, considering this representation "unbounded". Languages "yet to become" embrace a constellation of desirable traits, and they consider space, time, evolution and interactions for envisioning the future while grasping and activating the present.

New languages want to be the ink of the present to write the futures.

The unbound framework for New Languages



How to build unbound new Languages



Recommendations to lever new languages and formats

Interdisciplinarity requires the elaboration of new languages to describe and talk about it and to communicate on different theme areas. Future thinking needs to generate the conditions to find words that build new realities, to create new ways to communicate or build the future and new practices to imagine the future.

These 8 recommendations aim to facilitate the needed processes triggered by the "Unbound framework for languages yet to become".

1. **Support the creation of experimental spaces.** Fostering the creation of locations and institutional contexts that can act as spaces that do not belong to any disciplinary context will help to perceive that changes are possible and encourage to "play with possibilities".

2. **Foster immersive experiences.** Use multiple languages as a key to accomplish complexity. Theatre, dramatisation arts, and music could help understand complex issues such as global health, climate crisis, and the impact of technology on society. To teach complexity, introduce several actors with different roles and points of view and stimulate engagement through play.

3. **Foster the use of "tri-dimensional" thinking.** Overcoming a "binary perspective" (disciplinarity vs interdisciplinarity), and merging new professional identities that are based on interdisciplinarity is a cross-cutting need that requires decision-making support to promote them and bring them to life. This entails the use of multiple languages as a key to accomplishing complexity understanding.

4. **Go beyond frontal teaching.** Planning lessons starting from the end-user (the students). Promoting peer-to-peer exchanges among students, e.g. inverted classes.

5. **Inclusive programmes.** Enhance teachers' ability to adopt collaborative and co-constructive strategies, taing into account capacity and differences among students to discover the richness of diversity.

6. **Align with relevance.** To bridge the gap between formal and informal education and the critical issues of everyday life. Tackle themes and problems that students care about. Allow the outside world into the school, invite external experts and use sources coming from what is happening in our time.

7. **Make use of traditional and digital tools.** It is important to bridge the gap between teachers and students. To sustain the importance of sociability and relationships in building knowledge it is crucial to innovate language in school contexts. The human mind is social.

8. **Keep Educating Yourself, KEY is key.** To 'walk the talk' about futures thinking and how to integrate this approach into school learning, -formal and informal-, there is a real need for capacity building. Considering that every human being is a creative and potentially transformative being is not enough to grant the changes needed. Creativity is a muscle that needs to be trained. Therefore, training instances are key.

For more details, see the full Unbound Framework for New Languages here:
https://www.fedora-project.eu/deliverables/

3. Enhancing perceptions of and agency for futures

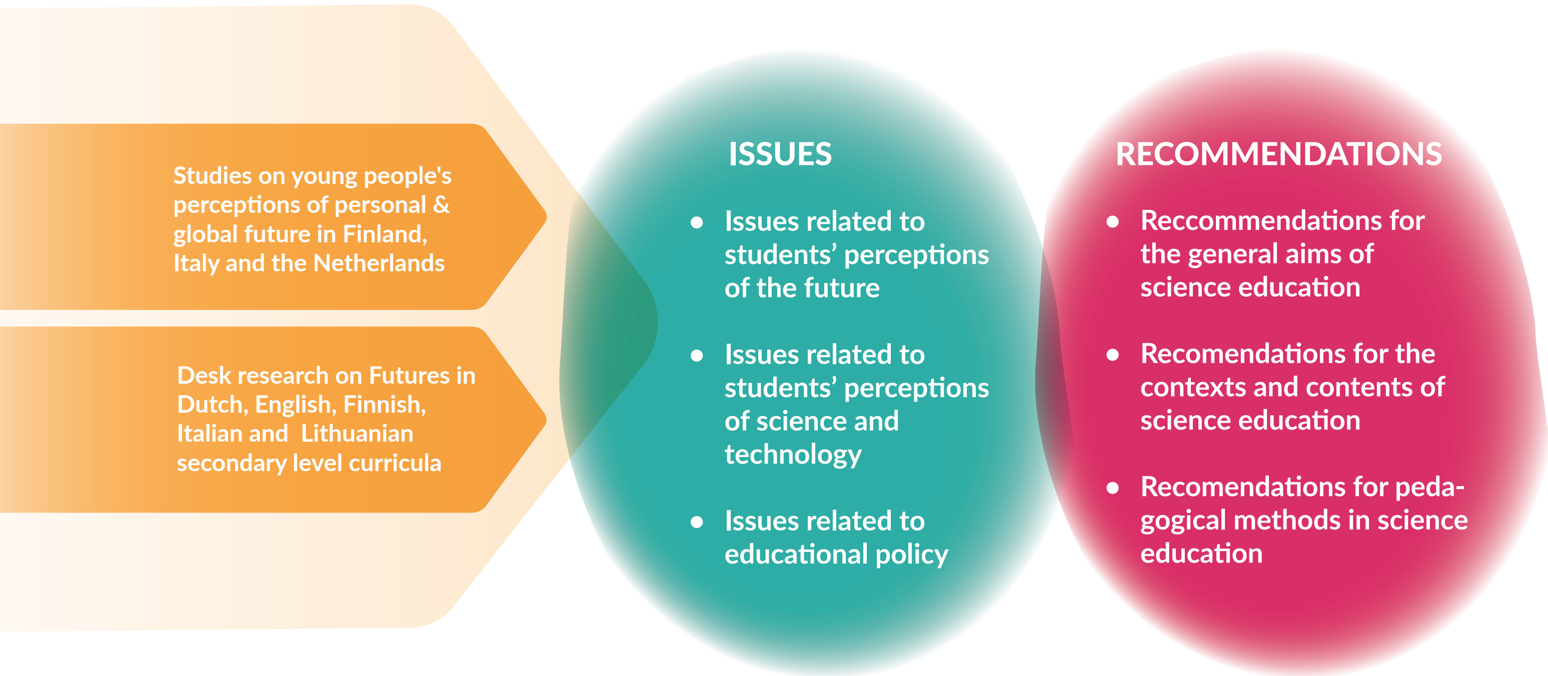
The global sustainability crises and the accelerating societal and technological development demand science education to address students' concerns and uncertainty towards the future. How do young people perceive their personal and global futures*? How do they imagine the role of science and technology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

Led by the University of Helsinki, five studies on young people's perceptions of the future and one study on European curricula were conducted. The empirical studies on students' futures thinking focused on their socio-technological images of the future, hopes, fears, perceptions of agency and tendencies for polarisations and "bubbles" in their thinking. The curriculum study identified explicit and implicit links to futures thinking skills in European science curricula for secondary schools.

Through these investigations, nine key issues to be addressed by future-oriented science education were identified. The nine issues involve issues concerning young people's experiences of powerlessness, detachment and polarization, issues in views of science and technology, and issues related to educational design and students' metacognitive skills.

Based on the findings of the studies, we propose a set of 14 research-based recommendations to futurise science education. The recommendations aim 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.

Towards future-oriented science education



Futures is commonly pluralised in futures studies and futures education to emphasise the idea that there is not only one possible future to consider.

Recommendations

The recommendations are grouped into three categories.

Why, for whom? — General aims for science education.
Recommendations especially for policymakers, curriculum developers and teacher educators.

1. Use futures thinking to cross, connect and contextualise 21st century skills
2. Incorporate future concepts and elements in science curricula
3. Incorporate futures thinking in science teacher education programs
4. Understand and address the personal, gendered, cultural, religious, socioeconomic and political dimensions of futures thinking and related beliefs
5. 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.

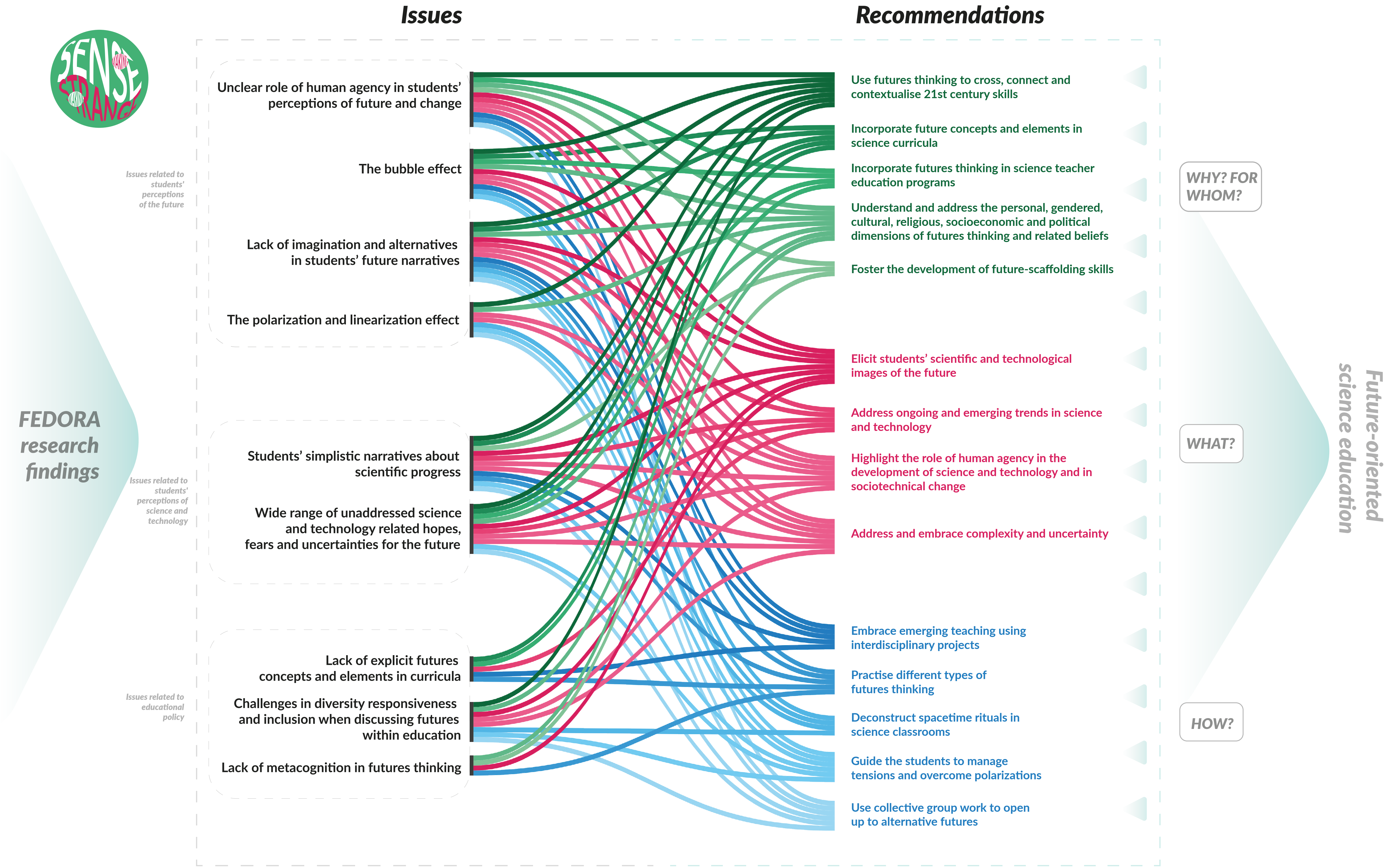
6. Elicit students' scientific and technological images of the future
7. Address ongoing and emerging trends in science and technology
8. Highlight the role of human agency in the development of science and technology and sociotechnical change
9. Address and embrace complexity and uncertainty

How? — Pedagogical methods in science education. Recommendations especially for teachers, teaching material developers and teacher educators. (see also the Future-Oriented Science Education Manifesto. Available here as well: http://bit.ly/fedoramanifesto)

10. Embrace emerging teaching using interdisciplinary projects
11. Practise different types of futures' thinking in the classroom
12. Deconstruct spacetime rituals in science classrooms
13. Guide students to manage tensions and overcome polarization
14. Use collective group work to open up to alternative futures

These results aim to 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. The following infographics illustrate the process leading to the research-based recommendations and how the recommendations correspond with the identified issues in a variety of ways. As a *framework*, the recommendations provide a broad and deep perspective on how to futurize science education.

Both the issues and the recommendations offer several openings for research agendas and projects. For example, there are open questions relating the concepts of agency, uncertainty and future-oriented competencies to science education.



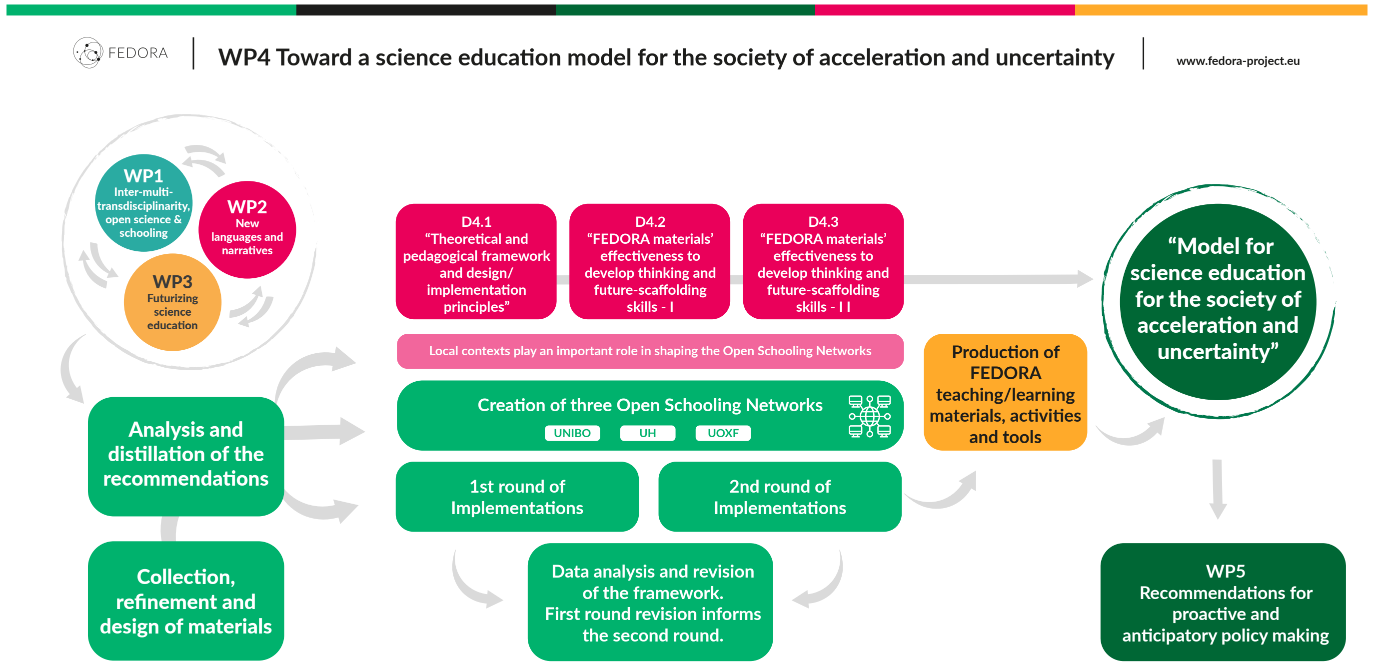
For more details, see the full Framework to Futurize Science Education here:
https://www.fedora-project.eu/deliverables/

4. Implementing Open Schooling

The implementation of FEDORA recommendations in school contexts is a challenge for the governance of the schools, teachers and students. It implies opening and questioning relational and epistemic elements that have historically characterised the educational systems and the professional identity of the teachers.

Led by the University of Bologna, empirical studies have been conducted to investigate the possibilities and the obstacles to change. Three Open-Schooling Networks, respectively in Bologna, Helsinki and Oxford, were in charge of producing prototypes or models to align science education with fast-changing science and society. They involved STEM[1] and SSH[2] 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.

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



1 Science, Technology, Engineering and Maths
2 Social Sciences and Humanities

In a dynamic dialogue between the FEDORA frameworks and their immersion into local experiences, the following highlights emerge from our research approach to the open-schooling design and practice:

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

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

- **Inter-multi-transdisciplinary knowledge challenges the professional trait of teachers as unique experts. It triggers new models of co-teaching**

The assumption that teaching needs to be grounded on new inter-multi-transdisciplinary knowledge organisation, poses new challenges to teacher preparation and teaching practices. Indeed, as shown in the first chapter of this handbook, to exploit the inner sense of interdisciplinarity, as well as to be consistent with the goal to align formal teaching with multi-actor and open research and innovation, new forms of co-teaching have to be imagined.

The design and implementation of prototype activities inhabiting the boundary of STEM disciplines and SSH disciplines require questioning the role of the singular expert (teacher) and the cohabiting of a plurality of expertise. The project's results highlight how interdisciplinarity allows to understand and solidify the position of an expert in the discipline but also implies redefining the role of an expert with respect to knowledge, colleagues (both the experts in the same discipline and others) and learners. Creating this co-design and co-teaching space turns schools into places where a plurality of professionals can collaborate to find ways to make the teaching experiences meaningful for the young. Reasoning in terms of co-design and co-teaching also questions their working schemes and the way in which instructional responsibility is distributed within this new complex space, where the specificity and the intersections of different disciplinary approaches emerge with mutual ownership, pooled resources and joint accountability.

- **The discovery of disciplines' inner meanings involves transiting and dialoguing with other disciplines**

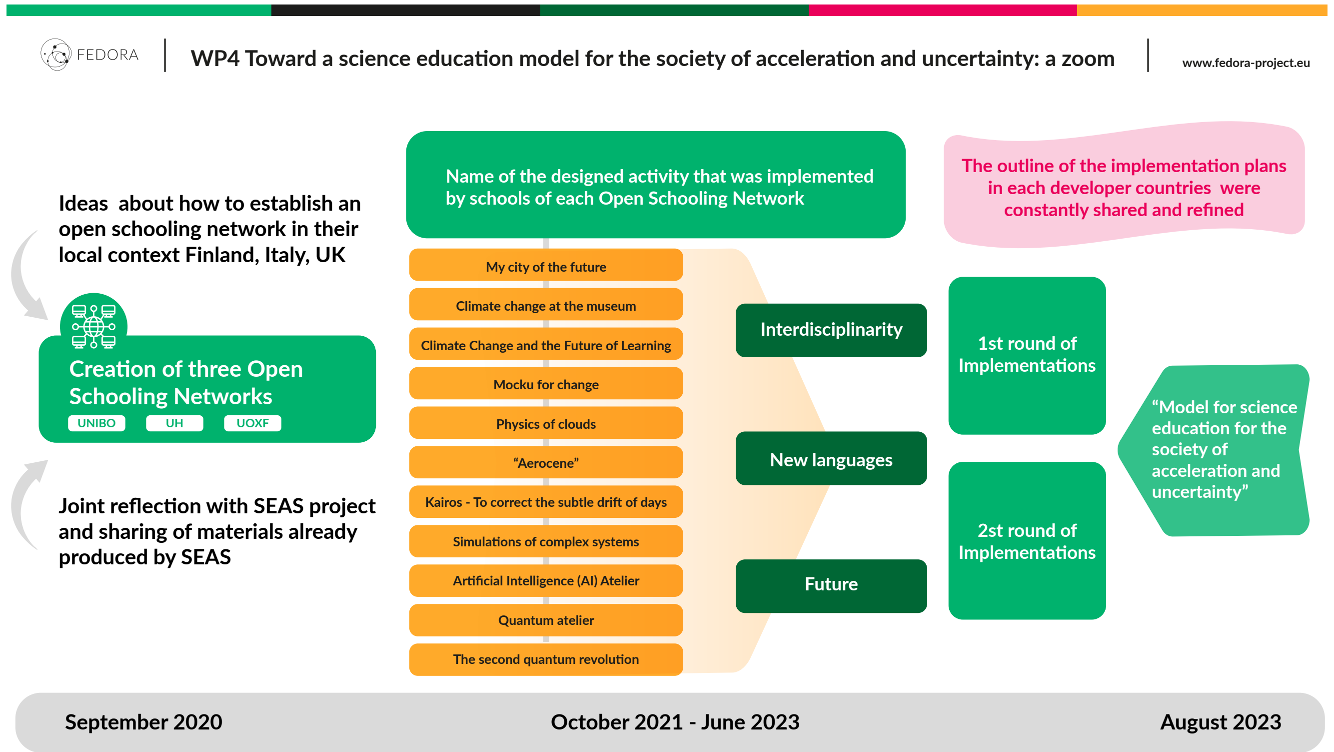
Several implementations involved STEM disciplines and arts, creating contexts in which young students could engage in an interdisciplinary project involving the authentic coalescing of languages. The establishment of a dialogue between disciplinary territories activated a process of translation from specific linguistic systems into others, creating the opportunity to enhance the communicability of STEM disciplines themselves. This process of translating scientific contents from one disciplinary language to another was intended to encourage a re-conceptualisation of the notions by clarifying and enriching their meaning and making them come alive in the search for personal meaning.

- **Grappling with the uncertainty and complexity of futures' thinking can act as an activator for "future-making"**

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

- **The change in future's perception through future-oriented science education does not go hand-in-hand with the narratives of change developed by students**

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



5. Making proactive and anticipatory policies

Education policies can determine how future-oriented science education can be enacted in schools. Hence, understanding policymakers' views is directly relevant to our goals in FEDORA because those views inevitably shape the decision-making, enactment and evaluation of proactive and anticipatory policies. The project employed Delphi methodology to delve into the judgements and opinions about future-oriented science education held by policymakers and professionals specialised in curriculum design, assessment, teacher education and higher education. Led by the University of Oxford, three rounds of questionnaires were distributed to a selected group of experts from the participating countries. The questionnaire in each new round captured and reflected participants' responses from the previous round so that experts' opinions could be pooled towards reaching a consensus. The following table illustrates the operations in the three cycles of the entire study.

The Delphi Process in FEDORA Project

Questionnaire	Completion	Number of respondents	Response rate
Round 1 (baseline)	March 2021	35	48%
Round 2	September 2022	22	63%
Round 3 (final round)	March 2023	18	82%

The key results from the final round of the Delphi study illustrate the extent to which the policy stakeholders have weighted various factors against some others in relation to promoting future-oriented science education. In each of the following boxes, the three most rated factors are shown in descending order of importance for the respective theme. Overall, the highest agreement levels were observed on questions related to competencies that students need for the future and what the future challenges are. Questions related to the European sustainability competence framework, policymaking, or reform resulted in lower agreement levels among the questionnaire respondents..

Central challenges for science and the future society

- Environmental issues (1)
- Societal tensions (2)
- Lack of trust in science (3)

Key competencies that students will need to address future challenges in science and society

- Critical thinking skills (1)
- Problem-solving skills (2)
- Creativity (3)

Competencies students need for envisioning the future

- Critical thinking (1)
- Interdisciplinarity (2)
- Imagination (3)

Ways to integrate competencies for imagining the future and addressing future challenges

- Inclusion of interdisciplinary approaches (1)
- Promoting imagination/creativity (2)
- Inclusion of socio-scientific issues (3)

Obstacles to reform of science education

- Rigid organisation of the curriculum (1)
- Teachers' perceptions (2)
- Lack of shared understanding between stakeholders (3)

Sentiment students should have in order to think about their own future

- A feeling of agency (1)
- A growth mindset (2)
- A sense of hope (3)

Sentiment students should have in order to think about the global future

- A feeling of agency (1)
- Informed about global issues (=)
- Aware of the impact of their actions on the environment (=)

Major obstacles to uptake of research in policymaking process

- Policymakers' insufficient understanding of research evidence (1)
- Limited openness by politicians (2)
- Traditional decision-making process (3)

Key components of effective policy to foster future-oriented skills

- Collaboration between stakeholders (1)
- Greater consistency in educational goals and the designed resources (2)
- Provision of teacher training opportunities (3)

Significance of the statements from the European sustainability competence framework

- Exploratory thinking (1)
- Adaptability (2)
- Collective action (3)

LEGEND

- 1 MOST IMPORTANT
- 2 SECOND IMPORTANT
- 3 THIRD IMPORTANT
- = EQUAL RANKING

NOTES

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A future-oriented model to enable creative thinking, foresight and active hope as skills needed in formal and informal science education

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