FEDORA

Deliverable 1.2

Framework for aligning science teaching/learning in formal contexts with the modus operandi of R&I: new inter-multi-transdisciplinary forms of knowledge organization for co-teaching and open-schooling
Draft version 4.0

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Dissemination level:

- PU: publicly available

Quality assurance

To ensure the quality and correctness of this deliverable, we employed an internal review and validation process. The deliverable was drafted by the work package leader (KTU) and elaborated in collaboration with the researchers of UNIBO. The results have been presented in several meetings, including the project meeting in Kaunas, where it emerged that another round of data analysis was needed to support the recommendation. A further crucial moment for feedback was the presentation during the multiplier event organized in Bologna, on November 4th, 2022. All partners contributed to comment the results and reviewed the document draft. Finally, the semi-final version was submitted to the project coordinator, for the final review and validation.

Version	**Date**	**Status**	**Author**	
V0	30/09/2022	Draft	KTU	Creation of the document as a report with the key findings
V1	17/10/2022	Shared with UNIBO	UNIBO provided feedback	Elaborated the framework, structure, contents with a focus on emerged issues
V2	04/11/2022	KTU presented to the participants of the multiplier event	Partners and other participants provided feedback	Corrections, suggestions and edits were conducted
V3	12/12/2022	Shared with the coordinator and UNIBO	The coordinator provided feedback	The document was revised
V4	19/12/2022	Submitted	KTU	

Table of Contents

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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Abbreviations and acronyms

AB	Advisory board
D	Deliverable
FEDORA	Future-oriented Science EDucation to enhance Responsibility and engagement in the society of Acceleration and uncertainty
GO	General objective
KPI	Key performance indicator
M	Month
NGO	Non-governmental organisation
R&I	Research and innovation
RFO	Research funding organisation
RPO	Research performing organisation
RQ	Research question
RRI	Responsible research and innovation
SDGs	Sustainable Development Goals
SO	Specific objective
SSH	Social sciences and humanities
STEAM	Science, technology, engineering, arts, mathematics
STEM	Science, technology, engineering, mathematics
T	Task
WP	Work package

Glossary

Barrier is a metaphor that is used by the project team to denote a borderline which separates disciplines or professionals and is hard to overcome.

Boundary is a metaphor of a borderline adapted by the project team from Akkerman & Bakker (2011) to model interdisciplinarity and its "paradoxical" nature: boundary both separates and connects.

Disciplinary or vertical knowledge organisation denotes structuring of knowledge into single disciplines via curricula, research management, internal institutional design (e.g. specialised departments), teacher preparation, logic of national level funding.

Interdisciplinary knowledge organisation encompasses all other forms of knowledge organisation that go beyond single discipline teaching, curriculum, education and research management etc. Examples of these forms may be cross-/multi-/transdisciplinarity which employ multi-teaching, open-schooling, project-based learning, STE(A)M education etc. as forms of science communication and learning.

Executive summary

The deliverable presents the findings from four part studies such as literature review, interviews, interdisciplinary study groups and surveys that were carried out under WP1 "Aligning science teaching/learning in formal contexts with the modus operandi of R&I". This WP aims to identify the limits and advantages of disciplinary knowledge organisation and boundaries or barriers it erects to the advantages of inter-/multi-/trans-disciplinarity in science education. By exploiting the advantages of both disciplinary and interdisciplinary approaches to science education and addressing the limits of present knowledge organisation it proposes a framework for aligning science teaching/learning in formal contexts with the modus operandi of R&I.

The framework integrates five issues that we named Divergence between *de jure* and *de facto*, Demands from teachers, Disciplinary isolation and lack of interdisciplinary language, Graduates unprepared for life, and Social insensitivity. Ways to addressing them are interrelated and are to be taken in combination at national and institutional levels if cognitive, emotional, epistemological, social-cultural boundaries at individual level are to be eliminated. Respectively, each issue is addressed by a set of recommended ways to tackling them. It is meant to strengthen science education that equips young people with interdisciplinary thinking and future-scaffolding skills. The key recommendations include setting up a safe and emotionally positive trading zone ("third space" – Bhabha, 1990) as a location and institutional context that does not belong to any disciplinary context, enable merging new professional identities that are based on interdisciplinarity and facilitate embracing the ambiguity of interdisciplinarity; designing a methodology to acknowledge uncertainty of one discipline to solve complex problems; developing the skills needed to accept the risk, embrace ambiguity and managing the equilibrium between sense making and "strange making" skills in a common coined language; auditing and redesigning organisational processes, in particular, human resource management practices to detect gaps constructing the hegemony of sciences, creating paradoxes, and discouraging interdisciplinarity.

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1. Introduction

Fast development of science and technology poses significant challenges to education systems globally. Educational systems have been criticised as static, rigid, and incapable to keep the pace of change (OECD, 2018). To address these concerns the FEDORA project aims to produce a new future-oriented approach to science education and to foster proactive and anticipatory policy making aimed to align science education with the fast-changing society and the modus operandi of R&I.

Particularly, WP1 “Aligning science teaching/learning in formal contexts with the modus operandi of R&I” aims to identify the limits of discipline-based (disciplinary) or vertical knowledge organisation and propose the ways to address them through inter-/multi-/trans-disciplinarity. Besides, it aims to build on the benefits of disciplinarity to construct a framework of science education that equips the young people with thinking and future-scaffolding skills. Therefore, **one purpose of WP1** is **to analyse** a variety of voices and perspectives on disciplinarity and inter-/multi-/trans-disciplinarity by experts in research performing and funding organisations, education policy makers and implementers, schools, and industry **and identify issues** that must be addressed by policy-makers as well as education managers. **The other purpose is to propose research evidence-based** recommendations for multi teaching and open schooling.

2. Objectives

The general objective (GO1) of FEDORA WP1 is to contribute to aligning traditional educational institutions (school systems and universities) with the ways R&I is produced so as to form new generations able to cope with and participate in the new modus operandi of R&I and to address the current and future societal challenges in a society of acceleration and uncertainty, according to responsible research and innovation (RRI) and the United Nations Sustainable Development Goals (SDGs). It translates into the following specific objectives (SOs):

SO1) To investigate the potential and the limits of the forms of knowledge organisation in disciplines that nowadays structure the educational institutions and to support universities and schools to recognise and break down the institutional, conceptual, social, professional, epistemological, and cultural barriers to science and social innovation induced by a vertical disciplinary organisation (contributing to overcoming the "silos" and "skill gap" effects).

SO2) To compare different disciplinary, inter-/multi-/transdisciplinary forms of knowledge organisation in terms of their limits and potentialities to develop, in the young generation, inter-/multi-/transdisciplinary thinking skills needed to grapple with the new methods and features of R&I and play an active role (as co-producers and/or users of scientific knowledge) in the society of acceleration, according to RRI and SDGs.

SO5) To create and analyse, in their inner dynamics, a variety of interdisciplinary and multi-actor communities and open-schooling networks in charge to produce prototypes or models to align science education with fast-changing science and society. The communities involve STEM and SSH researchers, researchers in science education, science educators (teachers, communicators etc.), philosophers and historians of science, experts in futures studies, RFOs, RPOs, sociologists, linguists, artists, citizens, entrepreneurs, NGOs, and students.

These objectives have been reached by **four part studies** (T1.1-1.8):
a) Literature review on the limits and potential of disciplinary knowledge organisation.
b) Cross-national interviews with representatives of research performing organisations (RPOs), research funding organisations (RFOs), schools and industry to identify limits and potential of disciplinary and inter-/multi-/transdisciplinary knowledge organisation.

c) Two interdisciplinary study groups consisting of experts with diverse backgrounds to investigate new (e.g. inter-/multi-/transdisciplinary) forms of knowledge organisation and offer insights into techniques of disciplinary boundary crossing.
d) Two cross-national questionnaire surveys with (i) high school and university students and (ii) experts in science education system such as education policy makers and implementers, education managers, and science teachers to identify potential, barriers and outcomes of a disciplinary and inter-/multi-/transdisciplinary approach to science teaching.

A main outcome of these part studies is this deliverable, i.e. report "FR1 - Framework for aligning science teaching/learning in formal contexts with the *modus operandi* of R&I" at hand. In the following part 3 it lists the research questions addressed by WP1 and then, in part 4, presents the methodology of each part study and highlights the key findings which enable understanding the scope and depth of the analysed RQs. In part 5, the findings from each part study are triangulated to develop issues and recommendations for addressing them. In the final part, the Framework for aligning science teaching/learning in formal contexts with the *modus operandi* of R&I is presented as recommendations for the design of materials and activities aimed to develop *thinking skills* needed by the young generation to get oriented in the complexity of the contemporary world and play an active role (as co-producers and/or users of scientific knowledge) in the society of acceleration.

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3. Research questions addressed by the part studies

Findings from WP1 address the following research questions (RQs):

- What potential and limits of the disciplinary organisation are perceived, observed or recognized by the various stakeholders involved in R&I, education, policy, entrepreneurial realm? What skills are formed by the given knowledge organisation? What new skills are needed for the young to grapple with the contemporary challenges and which science education should form?
- Is and if so, how is the current knowledge organisation diversity-responsive?
- What new forms of knowledge organisation do multiple stakeholders expect and what barriers in their implementation they perceive and anticipate? In particular, what institutional, conceptual, professional, social and cultural barriers to science and social innovation and to responsible research and innovation (RRI) can be ascribed to the current organisation of formal education into disciplinary paths?
- How can the universities and schools be supported in order to break down the barriers and, at the same time, to exploit the potential of the discipline-based knowledge organisation?
- What other forms of knowledge organisation can be elaborated with the potential to develop thinking skills needed to grapple with the new modus operandi of science and play an active role (as co-producers and/or users of scientific knowledge) in the society of acceleration?
- What forms of co-teaching and open-schooling can be implemented in formal contexts of science education, in order to exploit the inner sense of interdisciplinarity and to reproduce, in school practices, authentic multi-actors and open processes typical of current trends in R&I?
- If these new forms of knowledge organisation are implemented in contexts of formal education, are they effective to support, in the young generation, the development of new awareness about current (inter-multi-transdisciplinary, multi-actor and open) methods of science and to foster public engagement?

Next part of this deliverable outlines the methodology and key findings from each part study if they have not been presented elsewhere. In that case, references to venues where they can be found are provided.

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4. Studies on limits and potential of disciplinary vs interdisciplinary knowledge organisation

This part describes the four part studies carried out in T1.1-1.8 that yielded the data for evidence-based FR1.

4.1 Part study 1: Literature review

Methodological notes

Generating the query. The search terms were generated following the WP's RQs to cover the conceptual domain of the WP. They were based on 4 researchers' agreement, however, related and synonymic terms could still be missed. The query was generated using Scopus search engine as Scopus is known to index more publications than Web of Science.

The criteria for search were as follows: the keywords appear in titles-abstracts-keywords; references in the English language; references not older than 10 years; social sciences only. An experiment with every search phrase was conducted, trying to retrieve a smaller number of hits when faced with thousands of hits by putting a restriction to extract terms going together via apostrophes (e.g., "science education") or exact phrase via curly brackets (e.g., {science education}). Admittedly, in this way some important hits ("false negatives") could have been missed and some publications unrepresentative of the domain we are interested in ("false positives") may have been picked up. Finally, individual search queries were combined into one by using OR operator and put the above-mentioned restrictions. This yielded a list of approximately 1400 publications consisting of books, journal papers, and conference proceedings. The final search string is presented in Annex 1.

In addition, to supplement the efforts of defining the population of the conceptual domain of interest, the following actions were performed:

- Manually, by expert knowledge the "golden standard" papers were selected and then keywords to be used for a search in Scopus or other engines were extracted.
- Use of bibliographical network analysis from the search data already obtained and from other identified relevant publications by their centrality (or other) measures in the network.
- The mainstream journals publishing papers on STEM Education and Science Education were focused and publications were selected either by manual screening, supervised learning or unsupervised learning methods. This type of manual search for publications was employed in an unsystematic way.
- Finally, full texts of the selected publications were downloaded manually or in a semi-automated fashion and search of the phrases in full text documents was

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carried out.

Coding. The full text publications were manually coded with MAXQDA using the agreed upon codes. The following classification/coding scheme was devised and used to extract necessary information from the full texts and report the findings:

1. Potential and limits of the vertical disciplinary organisation
   1.1. What skills are formed?
   1.2. What new skills are needed?
   1.3. Diversity-responsiveness of the current organisation
2. Suggestions for improvement
   2.1. Other forms of knowledge organisation
      2.1.1. What thinking skills are they fostering?
         2.1.1.1. Are they fostering skills that are needed to citizens and professionals to participate in inter-multi-transdisciplinary, multi-actor and open contexts of RI?
         2.1.1.2. What are these skills?
      2.1.2. What barriers in implementation of suggestions to improve/other forms of knowledge organisation do stakeholders perceive and anticipate?
      2.1.3. How can universities and schools be supported in order to break down the barriers?
   2.2. Forms of co-teaching and open-schooling
      2.2.1. Are they effective?

Next, 2 broad categories and keywords in the full text documents were sought:

I. Potential and limits of disciplinary curriculum organisation:
- Curriculum
- Disciplinary curriculum
- STEAM vs STEM
- Science curriculum
- Skills development in disciplinary curriculum
- Potential of disciplinary curriculum
- Limits/barriers of disciplinary curriculum organisation
- Silos effect of disciplinary curriculum
- Social/gender barriers and science curriculum

II. New forms of curriculum organisation
- Curriculum forms
- Inter-/multi-/transdisciplinary curriculum
- 21st century citizens skills
- Learning in time of acceleration
- New learning models
- Open-schooling

- Forms of co-teaching
- New modus operandi in science education
- Formal/non-formal/informal science education
- Potential of secondary school in contemporary/ “new” science /STEM /STEAM education

The analysis of the sources was based on qualitative descriptions of the excerpts from the selected texts.

Findings. A global tendency highlighted in the discourse on education quality is characterised by a note of negativity. In particular, when it comes to the relationships between education and innovation, education and employability, also teachers' preparation, irrespective of disciplinary or interdisciplinary knowledge organisation. The themes of inadequacy, failure to produce, weaknesses emerge in the overall context of science education.

Another result from literature review is the ***definition*** of the bipolar terms of disciplinarity and inter-/multi-/trans-disciplinarity and, respectively, disciplinary/vertical and inter-/multi-/trans-disciplinary knowledge organisation. Knowledge organisation approaches are mostly dealt in the field of teaching and education and are often characterised through certain roles, actions, teaching and learning methods.

The conceptual components of ‘discipline’ diverged into two fields:

(i) Listing of the characteristics of the ‘discipline’ term, i.e. (1) the object of research; (2) a perspective or worldview, including assumptions; (3) a specialised body of knowledge related to their research, including specific language and terminologies; (4) a framework with theories and concepts, according to which the knowledge is organised; (5) specific methods to accomplish their research; and (6) some institutional manifestation such as academic departments and professional associations (Krishnan, 2009:9; Newell and Green, 1982:25 both as cited by Cuyegkeng, 2019:5).

(ii) Defining the term through the levels of differentiation for operational purposes, i.e. (a) Branch of knowledge - A broad clustering of disciplines with similar objects of study, frames of reference and methodological approaches, e.g., natural sciences and engineering; social sciences; the arts and humanities; the management sciences; (b) Discipline - an area of study “constituted by defined academic research methods and objects of study, frames of reference, methodological approaches, topics, theoretical canons, and technologies; [disciplines] may also be seen as “subcultures” with their own language, concepts, tools and credentialed practitioners” (Petts et al., 2008), and (c) Field of study - recognized areas of specialisation within a discipline or subdiscipline (CHED Task Force 57-59 as cited by Cuyegkeng,

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2019).

Disciplinary or vertical knowledge organisation is often referred to as a traditional approach in teaching and education. The paradigm organises knowledge into defined disciplines reaching back centuries. The teacher's role as a subject expert is to support students' acquisition of disciplinary knowledge, most often through the transmission model with the help of an authoritative textbook. Memorisation and rote learning are key strategies; students demonstrate their learning through correct answers on standardised tests. The traditional model is well entrenched, and continues to thrive worldwide (Adolfsson, 2018 as cited by Drake and Reid, 2020:2).

One of the key ***positive outcomes of the disciplinary organisation of knowledge*** is *deep learning*, which creates the value of engaging in the learning process. Feedback during the learning process is said to be powerful, and teachers can significantly increase students' motivation. Another advantage is that teaching based on the *disciplinary approach builds on existing knowledge and draws structural interconnections* between topics, which improves learning. This approach benefits from social learning when students learn both with and from one another through pedagogical approaches like peer tutoring and discussion groups (Brandt et al., 2021:2). Disciplinarity may also contribute to the effectiveness of learning by *communicating values* embedded in particular disciplines, the differences in and similarities between each science field more accurately (Quinlan, 2016:3; Tan and Hong, 2014:16).

As opposed to disciplinarity, interdisciplinarity relates to "integrative learning, a pedagogical approach whose focus is on helping students make sense of knowledge across curricula" (Holley, 2017 as cited by Ashby and Exter, 2019:2). Interdisciplinary teaching methods encompass applied learning approach, inquiry-based pedagogies, learner-centred approach (Tan and Leong, 2014:5), immersive, integrated curriculum (Schaefer et al., 2016:11), augmented reality inquiry games (Okada et al., 2019:4) or soundscape camps (Ghadiri Khanaposhtani et al., 2018:17).

Interdisciplinarity is not a novel approach in educational sciences. Cross-disciplinarity integrates "tools, ideas, or theories, mostly from neighbouring fields, in order to explain specific phenomena" (Holley, 2017 as cited by Ashby and Exter, 2019; Thompson Klein, 2010; Lattuca et al., 2004). Cross-disciplinary courses may also be taught by two teachers from different disciplines or a teacher who sought consultation from an expert in a different field. Multi-disciplinary teaching integrates several disciplines to one phenomenon or a theme, yet presents different approaches as juxtaposed to each other (Holley, 2017 as cited by Ashby and Exter, 2019; Thompson Klein, 2010; Lattuca et al., 2004). Unlike the cross- or multi-disciplinary approaches, transdisciplinarity encourages the creation of new or shared conceptual frameworks, both in terms of methodology and theory that transcend fields and integrate disciplinary perspectives (Thompson Klein, 2010; Rosenfield, 1992). In this case, a teacher serves as a guide who helps to connect content to support overall goals (Drake, 1991). This approach may include active involvement and collaboration with community and other stakeholders to co-construct knowledge (Choi and Pak, 2006; Holley, 2017 - both as cited by Ashby and Exter, 2019:2; Lattuca et al., 2004). STEM education is considered a case of an interdisciplinary, integrative learning model that makes use of project-based learning and inquiry in the classroom “to stimulate students to work more independently and critically to solve their country’s grand challenges” (as cited in El Nagdi and Roehrig, 2020:12).

There is evidence that interdisciplinary research and problem-solving foster at least four competency domains: systems thinking, boundary crossing, socio-cultural awareness, and integrative research (Wei et al., 2020:3). Interdisciplinarity is often viewed as a way to instil creativity, innovation, and synergy through collaboration, teamwork, application, and blurring of disciplinary boundaries (Haynes, 2017 as cited by Ashby and Exter, 2019:1). Interdisciplinary educational models such as STEAM are argued to have a positive effect on adapting curricula to students’ diversity, e.g. generating girls’ interest in STEM careers (Liao et al., 2016:6).

A discourse on skills as learning outcomes with a focus on (inter)disciplinarity is rich in describing ***21st century skills***. It also contends that interdisciplinary learning should top the disciplinary one (OME, 2002:3 as cited in Slomka, 2019:11). Therefore, teaching within the disciplines is important (Donald, 2009), but “rather than envisaging boundaries between disciplines, we could promote the concept that disciplines provide homes within the larger learning community” (p. 48). It is within this learning community that disciplinary knowledge can be brought in to inform the collaborative work of interdisciplinary or transdisciplinary curriculum (Costantino 2018:4) “to enable students to become effective citizens” who are able to connect local issues and global concerns (Rennie et al., 2012b:140 as cited by Rennie et al., 2018:16).

Numerous research papers distinguish a diverse range of 21st century skills. Examples of skills include: life and career skills; learning and innovation skills; information, media, and technology skills; leadership skills; creativity (Henriksen et al., 2016; Khine, 2017). There is a vast diversity of skills related to thinking forms such as computational, systemic, synthetic, dynamic, closed-loop (Atwater et al., 2008; Wing, 2006, 2011) thinking skills. They also relate to socio-cognitive and emotional skills such as self-regulation (Shear et al., 2010; Zimmerman, 2000), scientific or a narrower, STEM literacy and science self-efficacy, high tolerance for uncertainty, ambiguity, and contradiction (Bandura, 1997; Bybee 2010 both as cited in Falloon et al., 2020:3; Ritchie et al., 2011; Wei et al., 2020). The latter are seen as skills predicting civic participation in problem solving and decision making related to scientific issues (Dillon, 2009 as cited by Tan and Leong, 2014:4). Most of these skills are integrated into the concept of employability skills (Yorke and Knight, 2004 as cited by Vos, 2013:12). Relational skills such as collaboration also emerge in the discourse of 21st century skills

(Garcia et al., 2018 as cited by López-Faican and Jaen, 2020:2).

Moreover, ***socio-cultural competence*** is another theme of importance in the literature on 21st century skills. It embraces the skills such as 1) socio-cultural self-awareness, 2) socio-cultural contextual awareness, and 3) recognition of the ethical dimensions of decision-making in differing social contexts (Wei et al., 2020). In the context of STEM education, socio-environmental problem-solving emerges as a specific skill (ibid.). On the other hand, socio-emotional and socio-cultural skills which were in focus of revising or restructuring contents at different educational levels have received criticism, in particular, as applied to primary education. Young learners do not have enough experience to engage in reflection on socio-cultural context or socio-environmental problem solving, which results in incapability to apply the knowledge to practical situations in some contexts.

With respect to the FEDORA project, it is important to note that none of the covered sources in the literature review corpus specifically mentions ***futures thinking skills***, although the listed skills relate to future scaffolding skills such as predicting, imagining, acting with responsibility and consciousness about the impact of one's actions on social and environmental context.

Demands for 21st century skills raise expectations to teacher training as they are regarded as agents enacting STE(A)M. They must be prepared to lead the changes by introducing creative, project and research-based activities into classes (Anisimova et al., 2020).

More problem-focused findings from the interviews have been integrated in the description of the issues and recommendations identified in the sub-studies (see part 5).

4.2 Part study 2: Interviews

The part study was approved by the KTU Research Ethics Commission (protocol No. M6-2021-01 as of May 27, 2021).

Methodological notes

Instrument. A semi-structured questionnaire was developed based on the findings from literature review. A general interview questionnaire for representatives of RPOs was constructed and subsequently adapted to the other expert groups (RFOs, schools, business – see Annex 2). The general questionnaire consists of 6 thematic blocks: 0) An ice-breaking question to the research participant to know his/her experience in teaching/researching from the interdisciplinary perspective; 1) Evaluations of merits and shortcomings of current disciplinary organisation of knowledge considering the teaching/curricula, organisational design and research and its funding dimensions; 2) Skills formed by disciplinary organisation of knowledge, in particular eliciting reflection on its effect on forming 21st century skills; 3)

Diversity responsiveness of current knowledge organisation; 4) Barriers erected by this organisation to science, social innovation and RRI. In particular, insights on institutional and socio-cultural barriers and the ways they could be broken down in schools and universities were sought; 5) Suggestions for other approaches which could help develop skills to grapple with future challenges.

Sample. Convenience sampling was used to select experts for the interviews. From May 2021 to May 2022 6 interviews were conducted in Finland and the UK, 9 interviews in Lithuania, and 9 in Italy. In total, 30 interviews were conducted. Annex 3 summarises information about the interviewees. Backgrounds of some interviewees were eliminated for anonymisation purposes. Out of 30 interviewees, 11 were male and 19 female. 14 interviewees had background in natural and engineering sciences (most represented fields: mathematics, n=5 and physics, n=4), and 12 in social sciences and humanities (most represented field: education, n=4). Most interviewees (n=15) had work experience in RPOs, followed by the ones with experience in school (n=8), business (n=5) and RFOs (n=3). Out of the 15 with experience at RPOs 1 interviewee also had experience in an RFO, and 2 in school as teachers. Most of the interviewees had diverse role experience, combining duties in research, management and/or teaching. Two thirds explicitly mentioned responsibilities in managing an organisation, various university units or research projects.

Process of data collection and analysis. The interviews were carried out via zoom due to the restrictions of the pandemic COVID19. Audio records were transcribed. The transcriptions were anonymised for the analysis. Data coding followed the thematic blocks of the interview questionnaires. To ensure internal consistency, a two-stage coding process was used. First, two researchers rated the data, ascribing it to pre-defined codes. Next, a third researcher read through the citations ascribed to different codes and left a list of categories that were plausible from a critical reader's perspective.

Findings. Most interviewees had experience in teaching and research from both the disciplinary and the interdisciplinary perspectives. They acknowledged that the national model of education in their societies is dominated by the disciplinary knowledge organisation, taking a shift towards interdisciplinary one. In some countries some interviewees expressed stronger conviction about the shift towards the interdisciplinary, in particular, in education, cf.: "*…as far as I know it, the studies at the beginning are rather interdisciplinary nowadays and the bachelor programs are interdisciplinary… but the further you go, I guess, it gets more monodisciplinary*" (FIN02 RFO F), "*…UK is an early specialist system in the sense that people specialise at school by the end of school, and they also specialise very heavily, remarkably so in first degree level*" (UK04 Education RPO M). On the other hand, even in the contexts where national regulations direct both research and education to disciplinary knowledge organisation interviewees admit that *de facto* their study programmes and curricula as well as research are moving towards interdisciplinarity to be competitive and attract funding.

The interviewees were asked to evaluate the merits and shortcomings of disciplinary knowledge organisation from several perspectives, i.e. teaching/curricula, organisational design and research and its funding dimensions if they applied. From the reflections of the merits of disciplinary knowledge organisation, the themes of deep knowledge and proficiency in studies and research, identity-building and networking in research, value to business have emerged. A dominating theme in the shortcomings discourse of disciplinary knowledge organisation was skills as outcomes of disciplinary education, restrictions to making impact on society with the research findings, attracting funds for research projects and development of social innovation.

Further and more problem-focused findings from the interviews have been integrated in the description of the issues identified in the sub-studies and respective recommendations to address them (see part 5).

4.3 Part study 3: Interdisciplinary study groups

The interdisciplinary study groups research was approved by the Ethics Commission of the University of Bologna (Prot. n. 16657 del 26/01/2021).

Methodological notes
Two study groups were organized and carried out online from January to May 2021.
The first one, articulated in two workshops (January-February, 2021) had the following aims:

- To point out a draft FEDORA list of institutional, conceptual, professional, social, and cultural barriers to science and social innovation and to RRI that can be ascribed to the current organisation of formal education into disciplinary paths;
- To point out a list of interdisciplinary skills needed to grapple with the new modus operandi of science and play an active role (as co-producers and/or users of scientific knowledge) in the society of acceleration;
- To outline a common vocabulary to describe and compare different forms of knowledge organisation, as well as various typologies of inter-/multi-/trans-disciplinarity;
- To point out case studies to illustrate examples of inter-multi-trans-disciplinary forms of knowledge organisation.

The collected data were initially clustered. Clustering was the basis for ***building three***

narratives: a narrative of the barriers, a narrative of conditions that facilitate interdisciplinarity and a narrative of interdisciplinary attitudes and skills. The three narratives were checked, commented on and discussed both during the second study group and during the second project meeting involving the members of the Advisory Board.

The second study group was carried out (May 13, 2021) with the following aims:

- To discuss the results from the first study group, check the level of consensus and re-share the views of interdisciplinarity;
- To brainstorm on possible forms of knowledge organisation and participation to foster interdisciplinarity.

Participants. In the three workshops, respectively, 14, 12 and 11 people participated. In total, the sample included 16 unique persons with diverse professional profiles, background and interdisciplinary expertise (see Fig. 1-2).

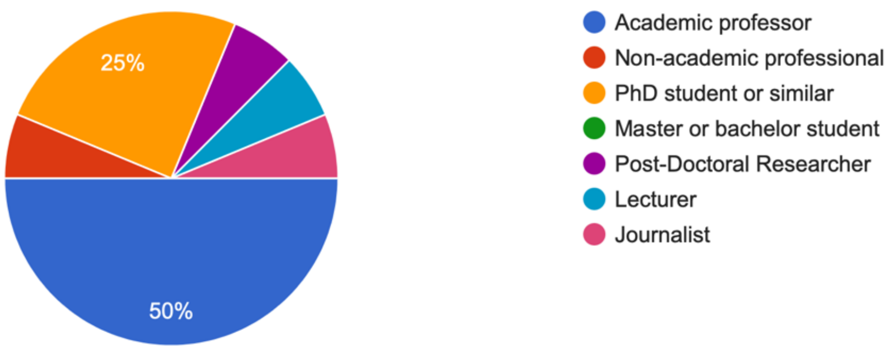

Figure 1. Professional profiles of the study groups participants

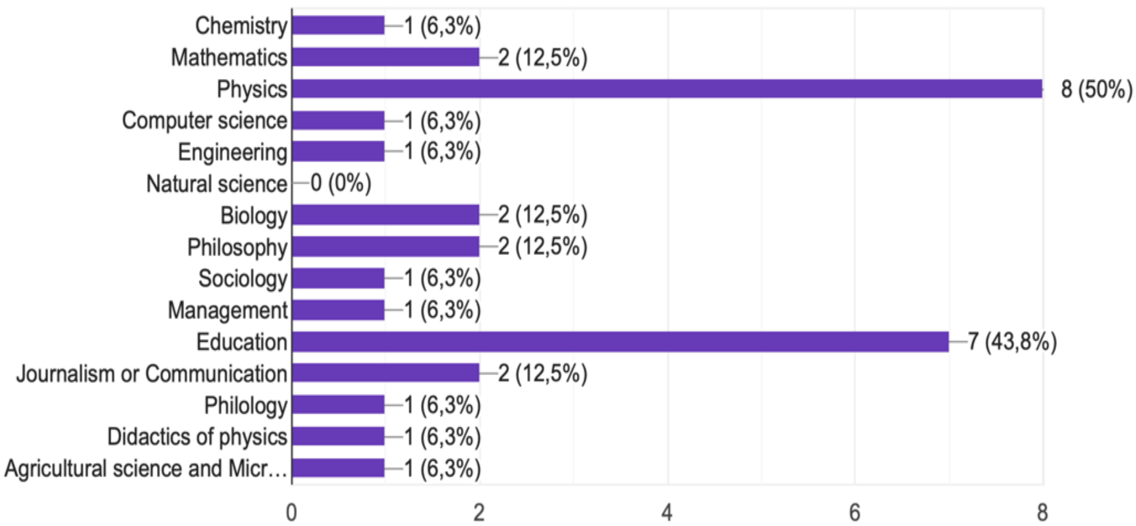

Figure 2. Formal education fields of the participants

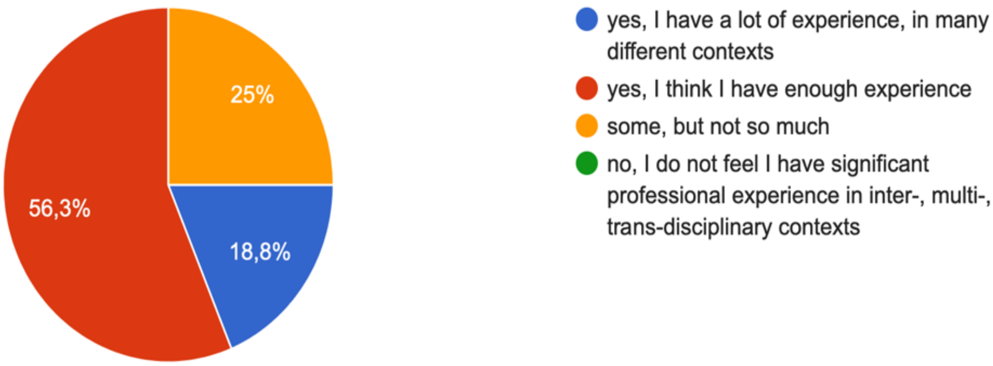

Figure 3. Participants' professional experience of interdisciplinarity

The members of the Advisory Board have been involved as experts to provide feedback on the documents and the results as well as to suggest recommendations for improvement.

Findings. The main findings of the interdisciplinary study groups regard the construction of shared narratives describing barriers, conditions for good experiences of interdisciplinarity, interdisciplinary attitudes and skills. An extract of these narratives is published on the website (https://www.fedora-project.eu/interdisciplinarity/). The barriers that emerged in the study groups were clustered into institutional, cultural, emotional, epistemological cognitive, linguistic argumentative. They are integrated into the description of the issues in part 5.

Starting from the study group, the partnership started to practice and learn **the language of interdisciplinarity as the language to inhabit a boundary zone** (Akkerman & Bakker, 2011), where it is needed to name and recognize how:

- to *hybridize* practices, *negotiate* meanings, *rediscover* one's own positioning with respect to the needed competences;
- to accept the *ambiguity* and *interpretative flexibility* of concepts and, at the same time, be able to recognize the specificities and different mechanisms of "*disciplinary closure of meanings*" (boundary making);
- to establish *communication connections* and build *translation methods* between one area of knowledge and another;
- to activate a *dialogic process of "othering"*, defining one practice in the light of another, outlining analogies and differences between practices;
- to put oneself in perspective and to know how to put oneself in other perspectives (*perspective making and taking*).

The ideas related to the conditions that can support effective boundary mechanisms refer to: a) specific contexts/locations and facilitation strategies, b) mood, attitudes and skills (integrated in the recommendations for issues – see part 5).

4.4. Part study 4: Surveys

Ethical approval for surveys with students and experts was issued by the Kaunas University of Technology Research Ethics Commission on February 28, 2022 No. M6-2022-04.

Methodological notes

Cross-country surveys with high school and university students and experts (teachers and others such as education policy makers, implementers at municipal and national level, study programme evaluators), in Finland, Italy, Lithuania, the Netherlands and the UK were carried out from February 28 to April 20, 2022. In Finland and Lithuania a raffle (lottery) approach with limited success was used to increase the attractiveness of the survey. From 444 students in high schools and universities (high school students N=314, university students N=130), 346 (high school students n=252, university students n=94) completed the survey, and from 67 (teachers N=43, others N=24) experts – 42 (teachers n=25, others n=17).

E-survey instrument Survey Monkey was used for collecting the data, and the data analysed with IBM SPSS 27.0 and R software. Typical statistical methods were employed for descriptive statistics, correlational analysis, exploratory and confirmatory factor analyses, structural equation modelling. More specific details of respective surveys are described below.

Students' survey

The aim of the students' survey was to test the relationships between their experiences of interdisciplinary science culture, science self-efficacy, interest in science and futures consciousness. Our working definitions of the conceptual components are as follows:

- Science culture as "a pedagogical dissemination of knowledge seeking to make it [...] accessible to non-experts" (Claessens, 2018: 13) is characterized by encouragement that students receive in both formal and informal educational settings to ask questions, debate on scientific concepts, relate scientific knowledge to real-life phenomena or given tasks to test ideas with a research study and draw conclusions from it, co-/multi-teaching, exploiting arts-based resources such as media, films, performances etc.
- Students' science self-efficacy is defined as students' confidence in their ability to conduct scientific research (Miles and Naumann, 2021).
- Interest in science is a construct consisting of cognitive, affective, and behavioral

components (Nyutu et al., 2022). Following the conceptualisation offered by Nyutu et al. (2022), the cognitive component of interest in science comprises evaluative thoughts and beliefs about science, the affective one – feelings and moods that a person experiences when studying science, and the behavioral one includes the behavioral responses or actions of a person, e.g. applying scientific knowledge.

- Futures skills were studied as the futures consciousness construct, which is part of the GreenComp or the European sustainability competence framework (Bianchi et al., 2022) construct and, according to Ahvenharju et al. (2018), consists of the dimensions of Time perspective, Agency beliefs, Openness to alternatives, Systems perception, and Concern for others.

Questionnaire development. Students' questionnaire was developed by using items and scales from PISA-2018 students' survey, Science Teaching Efficacy Belief Instrument (STEBI - Riggs and Enochs, 1990), students' science self-efficacy scale (Pintrich and de Groot, 1990), Futures consciousness scale (Lalot et al., 2021) and self-made items based on literature review (see Annex 4a).

Sample. Sequential tables summarize characteristics of university and high school students' by country, gender and type of school.

Table 1. University and high school students' samples by country

	High school	University	Total
Finland	7	24	31
Italy	44	26	70
Lithuania	175	37	212
Netherlands	26	2	28
UK	0	5	5
Total	**252**	**94**	**346**

Table 2. Gender frequencies in the sample

Gender	Frequency	Percent
Male	149	43.1
Female	181	52.3
Non-binary	9	2.6
Prefer not to say	7	2
Total	**346**	**100**

Table 3. Type of high school (type of finished high school for university students) by country

Schools by country	FI	IT	LT	NL	UK	Total
High school without emphasis on natural sciences ("lukio")(FI)	16					16
Other	7	2	3			12
High school with emphasis on natural sciences ("lukio, luonnontiedepainotus")(FI)	6					6
International Baccalaureate school or similar (FI)	2					2
Lyceum (ITA)		61				61
Technical or vocational school (IT)		5				5
International school (IT)		2				2
Gymnasium (LT)			207			207
General secondary ("vidurinė")			2			2
VWO (atheneum / gymnasium) (NL)				26		26
HAVO (NL)				1		1
VMBO / MAVO(NL)				1		1
Academy or free school (UK)					4	4
Grammar school (UK)					1	1
Total	31	70	212	28	5	346

Data analysis. Averages and percentages. Simple averages of items underlying each construct reveal considerable variation of such averages by school type, gender and country (Table 4). In absolute numbers (Likert scales for any individual item ranged from 1-totally disagree to 5 – totally agree) the lowest averages are exhibited by Science culture scale followed by Science self-efficacy, then Futures consciousness and finally Interest in science for both high school and university students' samples.

Table 4. Averages of scales by school type, gender and country

	Total	Gender		Country					**N**
		M	F	FI	IT	LT	NL	UK	**Total**
High school students									
Science culture (SC)	**2.96**	3.05	2.90	3.42	3.07	2.95	2.70		**251**
Science self-efficacy (SE)	**3.24**	3.42	3.10	3.10	3.74	3.18	2.86		**251**
Interest in science (IIS)	**3.66**	3.75	3.59	3.53	4.26	3.64	2.79		**250**
Futures consciousness (FC)	**3.56**	3.50	3.63	3.51	3.70	3.56	3.36		**252**
University students									
Science culture (SC)	**3.41**	3.40	3.44	3.41	3.21	3.58	2.44	3.59	**91**
Science culture at high school	**2.68**	2.79	2.53	2.54	2.63	2.78	2.81	2.87	**94**
Science self-efficacy (SE)	**3.52**	3.47	3.59	3.24	3.69	3.60	3.45	3.33	**94**
Interest in science (IIS)	**4.18**	4.12	4.23	4.12	4.21	4.19	4.14	4.21	**92**
Futures consciousness (FC)	**3.80**	3.79	3.82	3.81	3.79	3.79	3.78	3.87	**94**

The measurement scales were modified by dropping items that did not load well in exploratory and confirmatory factor analyses. The standard output from R package *lavaan* provides details on reliability of the scales or their components (for SC and FC constructs), see Table **5**. Two of the subscales - SC subscale on multi-teaching (mlt) and FC subscale 'Agency beliefs' (AB) - have quite low reliability coefficients.

Table 5. Reliability coefficients for scales and subscales

	SC_std	SC_tch	SC_mlt	SE	IIS	FC_AB	FC_CO	FC_OA	FC_SP	FC_TP
alpha.ord	0.879	0.872	0.674	0.957	0.932	0.601	0.822	0.773	0.888	0.734
omega	0.865	0.857	0.642	0.947	0.896	0.549	0.775	0.654	0.846	0.707
omega2	0.865	0.857	0.642	0.947	0.896	0.549	0.775	0.654	0.846	0.707
omega3	0.880	0.896	0.645	0.957	0.914	0.549	0.770	0.654	0.846	0.739
avevar	0.492	0.562	0.420	0.721	0.676	0.433	0.482	0.483	0.801	0.534

Legend: SC_std – Science culture of students, SC_tch – Science culture of teachers, SC_mlt – Science culture dimension of multi-teaching, SE – Science efficacy, IIS – Interest in science, FC_AB – Agency beliefs of Futures consciousness construct, FC_CO – Concern for others of Futures consciousness construct, FC_OA – Openness to alternatives of Futures consciousness construct, FC_SP – Systems perception of Futures consciousness construct, FC_TP – Time perspective of Futures consciousness construct.

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Correlations

Confirmatory factor analysis (CFA) model implied correlations among latent variables are reported in Table 6. Correlations among SC, SE, IIS and FC range from 0.292 to 0.599, $p<0.05$. Fit statistics of the CFA model were satisfactory: $X^2_{robust}(df=1064) = 1738.921$, $p<0.001$, $CFI_{robust}=0.951$, $TLI_{robust}=0.948$, $RMSEA_{robust}=0.043$, $SRMR=0.068$.

Table 6. Model implied correlations among scales and subscales

	SC_std	SC_tch	SC_mlt	SC	SE	IIS	FC_AB	FC_CO	FC_OA	FC_SP	FC_TP
SC_stud	1										
SC_teach	0.799	1									
SC_multi	0.798	0.771	1								
SC	0.910	0.879	0.877	1							
SE	0.266	0.257	0.256	0.292	1						
IIS	0.291	0.281	0.280	0.320	0.599	1					
FC_AB	0.192	0.185	0.185	0.211	0.268	0.393	1				
FC_CO	0.187	0.181	0.181	0.206	0.261	0.384	0.502	1			
FC_OA	0.225	0.217	0.217	0.247	0.314	0.461	0.602	0.587	1		
FC_SP	0.156	0.151	0.151	0.172	0.218	0.320	0.418	0.408	0.490	1	
FC_TP	0.172	0.166	0.166	0.189	0.240	0.353	0.461	0.450	0.540	0.375	1
FC	0.268	0.258	0.258	0.294	0.373	0.549	0.717	0.700	0.840	0.583	0.643

	SC	SE	IIS	FC
SC	1			
SE	0.292	1		
IIS	0.320	0.599	1	
FC	0.294	0.373	0.549	1

Structural model. Mediation model with statistical controls as common causes was tested with the R package *lavaan*. Fit statistics for the SEM model were satisfactory: $X^2_{robust}(df=1284) = 1998.273$, $p<0.001$, $CFI_{robust}=0.950$, $TLI_{robust}=0.956$, $RMSEA_{robust}=0.040$, $SRMR=0.067$.

It was found that the mediation of Science culture via Science self-efficacy and Interest in science amounts to half of the total effect of Science culture on Futures consciousness (Table 7, Figure 4). University students experience much higher levels of Science culture and somehow higher Interest in science than students at high schools; students from big cities have slightly lower scores on Interest in science; females tend to have much higher scores on Futures consciousness (Table 7). Science self-efficacy scores are not impacted by the control variables.

Table 7. The estimates and their p-values for the mediation model

To	From	Path id	P(>|z|)	Size of standardized path coefficient
Structural part				
FC <-	SC	d0	**0.032**	**0.145**
FC <-	SE	m1	0.232	0.080
FC <-	IIS	m2	**0.000**	**0.472**
SE <-	SC	d1	**0.000**	**0.291**
IIS <-	SC	d2	**0.000**	**0.263**
Correlation between IIS and SE			**0.000**	**0.558**
Mediation via SE (d1*m1)			0.243	0.023
Mediation via IIS (d2*m2)			**0.000**	**0.124**
Both mediation (indirect) effects			**0.000**	**0.147**
Total effects			**0.000**	**0.292**
Proportion of mediated total effect			**0.000**	**0.504**
Statistical controls				
SC <-	Female		0.280	-0.061
SC <-	Language		0.324	0.058
SC <-	Big city		0.122	0.094
SC <-	**University**		**0.000**	**0.342**
SC <-	Age		0.556	-0.042
IIS <-	Female		0.724	-0.019
IIS <-	Language		0.409	0.048
IIS <-	**Big city**		**0.035**	**-0.125**
IIS <-	**University**		**0.026**	**0.147**
IIS <-	Age		0.965	0.003
SE <-	Female		0.163	-0.079
SE <-	Language		0.362	-0.053
SE <-	Big city		0.764	0.017
SE <-	University		0.858	-0.013
SE <-	Age		0.608	0.042

FC <-	**Female**		**0.000**	**0.327**
FC <-	Language		0.620	0.024
FC <-	Big city		0.930	0.006
FC <-	University		0.508	-0.047
FC <-	Age		0.959	-0.003

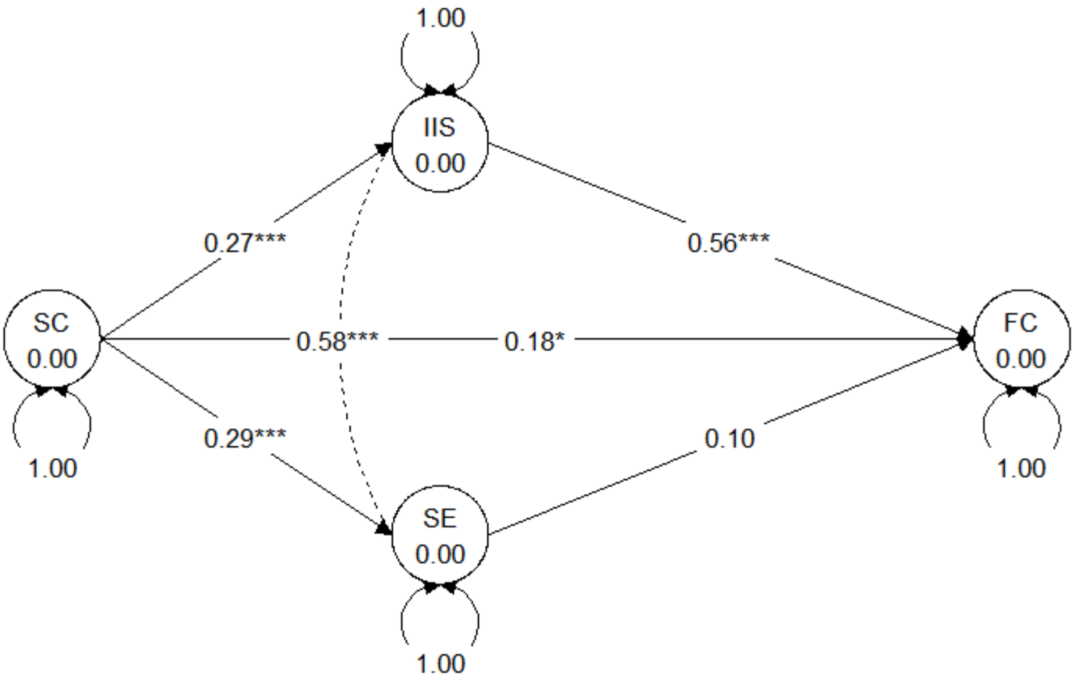

Figure 4. Mediation model results (structural part)

Experts' survey

Questionnaire development. The topics in the experts' survey to some degree followed the students' survey, e.g., in the case of Science culture indicators almost the same wording was used to assess the practices at high schools (practices at universities were excluded to make survey manageable for the respondents). The respondents could in expert fashion directly assess various aspects of interdisciplinary and disciplinary approaches. The questionnaire for the experts' survey is presented in **Errore. L'origine riferimento non è stata trovata.**4b.

Sample. Experts' sample by country is presented below in Table 8.

Table 8. Experts' sample by country

	Finland	Italy	Lithuania	Netherlands	UK	Total
Non-teacher	3	11	6	3	1	24
Teacher	8	14	10	3	8	43
Total	11	25	16	6	9	67

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Due to a small sample size in the experts' survey we only present results for the pooled sample dominated by Italian and Lithuanian respondents. Practitioners indicated (Table 9) that while some of the practices at science classes are more frequent, such as welcoming students' questions, being able to answer students' science questions or allocating extra time to explain science concepts other practices such as inviting professionals outside school as guest speakers, class debates about scientific research, allowing students to design their own research projects are less frequent.

Table 9. Practitioners' views on practices at high schools (items of Science culture construct, 1 – never, 2 - 1-2 times a year, 3 once every 2-3 months, 4 - once a month, 5 - almost every day)

	Average	N
When teaching science, I usually welcome students' questions.	4.23	44
Typically I am able to answer students' science questions.	4.11	44
When a student has difficulty understanding a science concept, I allocate extra time to explain it to her/him.	3.98	42
When students feel at a loss when studying science, I emotionally encourage them.	3.97	38
I explain how a scientific theory (concept, idea) can be applied to a number of different phenomena.	3.86	43
Students are given opportunities to explain their ideas.	3.84	43
When teaching science subjects, I relate the contents with other subjects.	3.63	43
I clearly explain the relevance of a scientific theory (concepts) to students' lives.	3.53	43
When teaching science, I rely on arts-based resources (e.g. films, media, visual arts).	3.5	42
Students spend time solving real life problems.	3.39	44
Students are required to argue about scientific/science questions.	3.21	43
Students are asked to draw conclusions from research they conducted.	3.12	43
In my classes students are encouraged to reflect on potential consequences of research and innovation.	3.12	42
Students are asked to perform research to test ideas.	2.75	44
Students are allowed to design their own research projects.	2.61	41
There is a class debate about scientific research.	2.61	44
Professionals outside school are invited to classes as guest speakers.	2.49	41

In experts' opinion (Table 10) interdisciplinary approach in education challenges the ways in which work at schools is organized, demands additional efforts for teachers' preparation and development, requires too much administrative effort (top 3 items describing interdisciplinarity), and the disciplinary approach is perceived as the basis of high school education, limiting students' ability to adapt knowledge to real tasks and giving superficial knowledge (top 3 items describing disciplinarity).

Table 10. Experts' views on the properties of disciplinary (1) vs. interdisciplinary (5) approaches

	Average	N
It challenges the ways in which work at schools is organized.	4.37	43
It demands additional efforts for teachers' preparation and development.	4.33	42
It requires too much administrative effort.	4.21	39
It helps students to perceive the interrelations between phenomena constituting the complexity of societal arrangements.	4.13	38
It creates social networking advantage to students.	4.02	41
It gives more opportunities to capture advantages of diversity of a students' group.	3.98	43
It opens up opportunities for diverse methods of teaching/learning (working).	3.95	43
It improves teachers' social skills (e.g. networking, teamworking).	3.93	43
It allows to deeply reflect impacts of the subject matter on society.	3.88	42
It enables real breakthrough.	3.87	39
It broadens teachers' knowledge about the topic.	3.83	42
It challenges teachers' scientific identity.	3.83	42
It increases institutional resilience.	3.81	36
It facilitates growth of students as personalities.	3.8	41
It creates skills advantage to students.	3.74	43
It strengthens students' skills to act in public interest.	3.74	43
It is emotionally engaging for both teachers and students.	3.68	41
It increases national resilience.	3.57	37
It helps teachers to capture students' talents.	3.45	42
It favours teachers' career progress.	3.42	33
It creates knowledge advantage to students.	3.39	41
It promotes teachers' beliefs in their capabilities to attain learning outcomes.	3.25	40
It allows for specific feedback.	2.9	40
It is the basis of high school education.	2.72	43
It limits students' ability to adapt knowledge to real tasks.	2.58	38
It gives just superficial knowledge.	2.54	35

Experts see (

Table 111) interdisciplinary approach as more favourable for producing collaboration skills, appreciation of diversity in society, creativity skills (top 3 skills describing interdisciplinarity), while the disciplinary approach is better for career orientation, scientific identity, academic

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achievement (top 3 skills describing disciplinarity).

Table 11. Experts' views on the skills produced by disciplinary (1) vs. interdisciplinary (5) approaches

	Average	N
Collaboration skills	4.17	42
Appreciation of diversity in society	4.13	39
Creativity skills	4.02	41
Leadership skills	3.93	41
Sustainability skills	3.93	41
Participation in public decision making	3.9	40
Futures consciousness	3.87	39
Problem solving skills	3.83	41
Employability skills	3.76	41
Affective engagement with disciplines	3.6	40
Self-efficacy	3.41	41
Personal identity	3.38	42
Self-regulation	3.37	38
Career orientation	3.26	39
Scientific identity	2.61	41
Academic achievement	2.56	41

This ranking of skills as generated by the analysis of experts' attitudes supports the findings of the other part studies such as literature review and interviews.

5. Identified issues

Part-studies of WP1 identified five major issues which are further elaborated and preliminary recommendations for addressing them are identified. These issues include: Divergence between *de jure* and *de facto*, Demands from teachers, Disciplinary isolation and lack of interdisciplinary language, Graduates unprepared for life, and Social insensitivity.

Issue 1: DIVERGENCE BETWEEN *DE JURE* AND *DE FACTO*	**National regulations and institutional inconsistencies obstruct interdisciplinarity, institutional competitiveness and social impact**
Elaboration	Although interdisciplinarity is promoted by national strategic programmes and international research funding is available to direct RPOs' initiatives to practise it, national criteria for institutional research assessment and funding still promote disciplinarity. National study programme accrediting bodies, research funding institutions operate in a disciplinary way and maintain the status quo (Gröschl and Gabaldon, 2018). "*Despite initiatives to support boundary crossing knowledge practices in research and curriculum in the university, the disciplines persisted as a structuring force, enacting a tension between the policy discourses of interdisciplinarity and governance processes of teaching*" (Woelert and Millar, 2013 as cited by Hannon et al., 2018:13). At institutional level, structural changes are made in RPOs to create diverse research teams to address grand challenges, yet, these processes are not tuned with human resource management. The divergence between the policies and strategies of interdisciplinarity on the one hand and their implementation and governance on the other hand create a tension and loss of direction to be pursued by individuals acting in this system. As a result, interdisciplinary curricula may become fragmented or shallow (referred to as the "potpourri" problem – Jacobs (1989)), too broad (sacrificing depth of knowledge, authenticity of disciplines), failing at disciplinary rigour and development of skills to solve complex problems (Erdogan and Stuessy, 2015; Vincent and Focht, 2010; Wineburg and Grossman, 2000), marginalizing disciplinary teachers (referred to as the polarity problem – Jacobs (1989)) or lack

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	benchmarking (cf. Davies and Devlin, 2010:21; Slavit et al., 2016:2). In this respect, interdisciplinarity is viewed as more suitable for addressing complex research and social problems (Zerhouni, 2003:64 as cited by Begg and Vaughan, 2011:3).
Empirical basis	Although interdisciplinarity is promoted by national strategic programmes and international research funding is available to direct RPOs' initiatives toward it, national criteria for institutional research assessment and funding still promote disciplinarity: "*…if you follow all the instructions, all regulations and all the requirements which are provided by our quality assurance centre, it means, that it's only one possibility - to have a disciplinary study programme*" (LT07 Economics RFO and RPO F). At institutional level, structural changes are made in RPOs to create diverse research teams to address grand challenges, yet, these processes are not tuned with human resource management, which results in tensions to individuals and raises barriers to innovation development or considering social impact of technological development. To illustrate, a research article published in a top-tier journal in one science field (e.g. natural or physical sciences) may not be counted as a high achievement in the other (e.g. social sciences or humanities) when assessing the researcher's output during the employment term: "*So imagine, our university, they pay remuneration like prize for preparation, right, for the ISI articles. …imagine, our top dream, but it will not qualify for me as a social scientist …*" (LT02 Sociology RPO F). Findings from the interdisciplinary study groups add on this observation: *Interdisciplinarity is a very relevant topic, but institutions (e.g. through formal school programs or through systems of reward, promotion, evaluation, funding) do not provide real guidance on how to manage interdisciplinarity. In many cases, the creation of inter-trans-multi-disciplinary collaborations is in fact hindered by evaluation/legitimation/accountability criteria in the institutions, together with specific funding systems.* Disciplinary funding may seem simple from the research funding administration perspective but in the long run it undermines university and national competitiveness: "*…for the sake of simplicity, working on a disciplinary framework is easier. … but [it] is not the best solution because in the long run, you perform worse. You get less funding. You don't address properly problems posed by society, by research, by challenges*" (IT07

	Philosophy and law RPO M). Cultural aspects induced within institutional domains manifest themselves as perceptions that become implicit assumptions, rituals, habits of minds and can emerge as emotional barriers.
Recommendations	At system level, **re-engineering governance and changing institutional processes** must take place: key performance indicators, funding formula of RPOs, adding qualitative criteria to quantitative ones in the criteria of staffing, coordination, performance assessment, workload allocations are seen as the prerequisites to ensure sustainability of interdisciplinary courses (Hannon et al, 2018:14; Klein and Falk-Krzesinski, 2017). Interview findings also suggest remodelling of criteria for evaluating research: 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. Hence, assessment of RPOs should follow this line as well. Emphasis on collaboration at institutional level may contribute to maintaining teacher teams with the mindset of co-ownership of interdisciplinary courses (Hannon et al, 2018:12-13) and hence help to deconstruct institutional and cultural barriers in educational institutions.

Issue 2: DEMANDS FROM INDIVIDUALS	**Practising interdisciplinarity is challenging to teachers and researchers**
Elaboration	Interdisciplinarity requires expertise in several disciplines that one teacher usually cannot possess. In addition, it demands student-centred pedagogy and more dialogical forms of science communication with students (Bickmore, 2014:2). Therefore, moving towards interdisciplinarity threatens teachers' authority and self-confidence. Integrating technology within any subject area may be time consuming and complex to teachers (Hickey et al., 2012; Roschelle et al., 2013; Scanlon et al., 2011; Sharples et al. 2015 – all as cited by Chang et al., 2020:2), which educational institutions do not consider when transiting to interdisciplinary curricula and teaching practices. At university level, not all researchers feel competent at and comfortable with combining different research methods and designing

	transdisciplinary frameworks (McNair et al., 2015:5). Epistemological and cognitive barriers forming the disciplinary identity of professionals of various disciplines can be created by the discipline itself, taking into account its goals and values, practices, methods and ways of systematising knowledge.
Empirical basis	Based on the evidence from interviews, teachers' qualifications, motivation and time constraints to connect different disciplines were pointed out as possible causes for failure to engage in interdisciplinary teaching. Teachers may feel unsafe in interdisciplinarity because of identity loss: *Besides the funding problem, besides, you know, the recruiting problem and the publication, the ranking of researchers, there's also an issue of identity of researchers* (IT07 Philosophy and law RPO M) or feeling excluded from research groups in the institution because of strong scientific identity. This finding was supported by the data from the interdisciplinary study groups: *Professionals in the various disciplines have, hence, their **disciplinary identities** that can emerge in interdisciplinary contexts as obstacles. **Emotional barriers** that may emerge in interdisciplinary contexts are represented, for example, by the feeling of **discomfort**, or a sense of **insecurity** about one's own role and expertise.* The findings from the survey of experts indicate that the interdisciplinary approach in education challenges the ways in which work at schools is organized, demands additional efforts for teachers' preparation and development, requires too much administrative effort (top 3 items describing interdisciplinarity).
Recommendations	Prior research gives evidence that interdisciplinary subjects persist if there is a stable **core teaching team** (Hannon et al., 2018:11). Hence, institutions should pay attention to their recruitment, development and retainment practices. Developing **supporting materials** such as simple data sets, lesson templates, local and international case studies and hands-on activities and experiments for teachers could eliminate the issue of limited time possessed by teachers (Reis and Ballinger, 2020:7). Some of these needs are addressed by the FEDORA project.

	Based on the interview data, a coping strategy of a "**disciplinary nomad**" may be developed by individuals themselves as they work in interdisciplinary research groups, which helps to overcome the cognitive and epistemological barriers: *"And if you have just at some point to lead the group, a lab and things like that, you have just to escape for the simplicity and the comfort zone of your job, where you have a lot of fun, and so you start to understand the importance of complexity in a more general way in which you don't mix only complexity in your field, but complexity in human relation, in different disciplines, in different languages. And … you train yourself somehow in just getting along with this complexity, which is a lot of fun, not only fun sometimes, but I mean is normal in the life"* (IT09 Physics RPO M). To overcome emotional barrier in the form of individual mood and attitude, interdisciplinary study group data suggest *turning knowledge exchange into a pleasing experience, e.g. adopting an "acceptance and/or a "recognizing/valuing" mood. Acceptance concerns a large variety of dimensions: accepting intellectual risk, lack of closure, embracing ambiguity, going out of the comfort zone, recognizing otherness as source of knowledge and competence, acknowledging not to have individually all the knowledge and competencies required or that the process of interaction is slower than usual.* The interview and interdisciplinary study group findings indicate that institutions can facilitate the development of a common interdisciplinary language and overcoming the barriers by **establishing a "a third space"**, be it a physical or a virtual one. This is seen as a method to change the modus operandi of the current knowledge organisation and challenges created by it: "*…we had a very short teaching and learning briefing every Wednesday morning. … there were several topics covered by teachers from different disciplines. So essentially they were all talking about the same thing, but they showed how they approach it in their subject area*" (UK02 School F). Interdisciplinary study groups: *Boundary crossing mechanisms are "**learning potentials**" that need to be activated. Their activation can be facilitated if the "**trading zone**" is properly created or if it occurs in "new contexts" or "**third spaces**", where habits are given up and roles of participants are clear or have been made clear . "Third spaces" can be, for example, locations or hubs for innovation, or even primary teacher education institutes, where there are trans-disciplines like primary education.* *To scaffold a "**safe third space**", a solid plan for discussion - a*

	*"**choreography**" - must be designed and consistently managed by a facilitator. This means that, when the roles and the structure for discussion are not clearly determined by the special **context**, then **principles** and "**rituals** to embrace the ambiguity of interdisciplinarity" (e.g. rituals for going out and coming back the comfort zone, of inspiring creativity and converging to the personal area of expertise…) need to be shared and implemented.*

Issue 3: DISCIPLINARY ISOLATION AND LACK OF INTERDISCIPLINARY LANGUAGE	**Disciplinary isolation and lack of interdisciplinary language to talk across different perspectives**
Elaboration	Disciplinary knowledge organisation as entrenched by departments, faculties, specialized vocabulary and forms of practice creates a 'silo' effect, which constructs social, cultural and institutional barriers as well as cognitive and epistemological boundaries to interdisciplinarity in educational institutions. Organizing into faculties and departments prevents from finding a common interdisciplinary language and understanding how knowledge could be exchanged (Iacobucci and Micozzi, 2012 as cited in Kazakeviciute et al., 2016:4). Institutional processes such as career planning and assessment practices at universities cluster academic community into closed cultures (Gröschl and Gabaldon, 2018; Hannon et al., 2018:14). As criteria to measure outcomes of interdisciplinary research are missing, a single discipline choice is often chosen as a safer approach (McNair et al., 2015:5) to attract research funding, advance in career or measure learning outcomes. This also results in lack of clearly set standards for assessment of students, which may undermine students' achievement of the learning goals (Khine, 2017:24; Slavit et al., 2016:9). As a result, sticking to the closed culture of disciplines erects a barrier to innovation teaching (and development) as a single content discipline is not able to "house" innovation (Uskov et al., 2015:384). Strong disciplinary identity and missing common interdisciplinary language create epistemological and cognitive boundaries for individuals.

Empirical basis	The issue is evidenced by the findings from both interviews and the interdisciplinary study groups. The theme of different languages being used even in adjacent disciplines is recurrent, e.g. "*…if you talk now in our faculty with a person who does particle physics, axiomatic theory, solid state physics, astrophysics, sometimes they don't even have a common language"* (IT09 Physics RPO M). Noted also by interdisciplinary groups: *Furthermore, academic and school culture more or less implicitly seems to produce a "**culture of closure**". Culture of closure is created, for example, by valuing more dissensus and specific forms of disciplinary expertise rather than abilities like: consensus building, capacity to legitimize other's role or expertise in multi-/inter-disciplinary teams (skills in convincing others and/or recognising others), capability of bridging, ability to understand the cultural and social background that frames or influences one's view/perception/reaction.* *Disciplinary closed communities, in order to strengthen their **identities**, develop proper **symbolic languages, representations and communication practices**. When languages are competing, it can happen that there is little motivation to change.* Different languages build epistemological boundaries and limit cognitive skills once addressing different problems: *interdisciplinary teamwork is not only difficult at the epistemological levels, but also for the lack of cognitive skills that are not so relevant in disciplinary contexts, like thinking out of the box, finding a common background, understanding the common goal and imagination and curiosity, and the ability of moving between roles of expertise and non-expertise in different phases of the work and being able to adapt the description of your expertise to the kind of interlocutor, to make it understandable.*
Recommendations	Literature review findings suggest that introducing new development programmes to the academic staff that are oriented to **learning other participants' world views** through critical "conversations between disciplines, whilst retaining the integrity of those disciplines" (Davidson, 2004:302) could help to cross the boundaries. Also, teacher training programmes should be extended to embrace evaluation of interdisciplinarity with, e.g. "*qualitative measures which focus on student maturational development involving portfolio analysis*" (Davies and Devlin, 2010:27). Conley and Darling-Hammond (2013) assert that measurement of achievement should focus on deep learning as

	manifested by *"higher order cognitive skills, and more importantly, skills that support transferable learning, and abilities such as collaboration, complex problem solving, planning, reflection, and communication of these ideas through use of appropriate vocabulary of the domain in addition to presentation of projects to a broader audience"*. These methodologies could be a contribution to advancement of interdisciplinarity in practice (Grover et al., 2015:10). "Third spaces", which was a recommendation to issue 2, can act as enablers for finding a common language: *Ability to ask questions, to listen, to share knowledge, to create personalised entry points for every participant gives opportunity to change or to create rules and teaches/allows to accept different perspectives, which enables boundary-crossing* (Interdisciplinary study groups). At system level, **changing institutional processes**: adding qualitative criteria to quantitative ones in the criteria of staffing, coordination, performance assessment, workload allocations are seen as the prerequisites to ensure sustainability of interdisciplinary courses and promote research integrity as part of responsible research and innovation (Hannon et al, 2018:14; Klein and Falk-Krzesinski, 2017; Mejlgaard et al., 2020). Emphasis on collaboration at institutional level may contribute to maintaining teacher teams with the mindset of co-ownership of interdisciplinary courses (Hannon et al, 2018:12-13). Focus on the problem that a course helps to solve rather than on different approaches and languages of dissent can help to cross the described cognitive and epistemological boundaries. Interdisciplinary study group discussions suggest that search for common language in interdisciplinarity in STEM education entails *managing a particular kind of equilibrium* that we called "***between sense-making skills (systems, critical, analytical thinking) and strange-making skills (creative, imaginative, anticipative thinking)***" *beside 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).* The "strange-making skills" can also be triggered by **cultural transposition** as exemplified by the interview data, which enables cognitive and epistemological boundary crossing: "*I think that you have*

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	the opportunity toward the development of disciplinary knowledge, also to know better yourself and in this sense, you have more chance to do it if you have different path of this learning journey, in particular talking about these cultural transposition, that it is the terms we use in mathematics education, when we look at the insights that you can get from the meeting with a different educational practice coming from a different cultural context, In this research approach, we talk about to unthoughts (inpensati)" (IT05 Mathematics RPO F). Accepting the intellectual risk, embracing ambiguity and managing the equilibrium "between sense-making and strange-making skills" appear interesting "constructs" to be further explored, since it regards the tension between disciplinary identities and inter-disciplinarity. In FEDORA disciplines and their epistemological cores are considered crucial to guide the students to make and consolidate "structured" educational experiences. Such experiences represent a solid ground that is needed to develop "sense making" skills and from which a student can take up the process of crossing the boundaries and developing strange-making skills.

Issue 4: GRADUATES UNPREPARED FOR LIFE	**Disciplinary knowledge organisation does not prepare graduates for work life and beyond**
Elaboration	The focus of educational institutions on procedures and mastery of methods (Polikoff, 2015 as cited by Belland et al., 2017:24), pedagogical methods used in the disciplinary approach have been criticised for failing to produce skills to apply the knowledge and the learnt tools to practical problems: "This [disciplinary] focus is no longer sufficient to meet the various stakeholder needs for graduates with contemporary workplace professional attributes, understandings and skills (Litchfield, Nettleton, & Taylor, 2008 as cited by Litchfield et al., 2010:1)". Technical programmes have received criticism for failing to develop not only technical expertise (due to lack of practical experience during the study years) but also communication, leadership and management skills that students consider important to employability (Pasovic et al., 2018: 5). Moreover, disciplinary approach to knowledge organization is seen as erecting systematic barriers to developing transferrable skills needed by labour market and practical life, e.g. applying conceptual knowledge to

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	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 threat to produce innovation. Teaching methods applied in a disciplinary approach seem to fail to produce discussion and decision-making skills: "*Traditional lecture methods applied to large classrooms seem in this light more and more inadequate to our fast-changing societies, as they do not promote discussion and are adverse to problem-solving attitudes* (Cowan 1999 : 33)" (as cited in Khan, 2016: 97). Contrariwise, a multidisciplinary approach that produces graduates with "a more balanced understanding of the world" is seen as developing particular disciplinary skills that are desired for employment (Krishnan, 2009:42 as cited by as cited by Cuyegkeng, 2019). "*...the societal context of socio-environmental problems, along with the need to develop solutions that are embraced by stakeholders with often competing agendas, necessitates a transdisciplinary approach (Mobjörk, 2010), transcending disciplinary boundaries and engaging perspectives and actors beyond academia*" (Wei et al., 2020:1).
Empirical basis	Interview data suggest that rather generic social skills and, in particular, communication skills are still scarce among graduates with a disciplinary education: "*They are going to really strong substance areas, really good domain expertise, but the kind of skills to find relevant information, analyse it, form scenarios, deliver these, I would say, findings in an interesting appealing format, to stakeholders, customers, colleagues, general audience... For example, these are skills that the graduates at the moment don't have, whether it's in high school, comprehensive school, graduate [schools]*" (FIN05 Business M), "*Maybe that discipline is prepared, learned, but how to continue living in the world and how to communicate is not. Everyone gets this through practice*" (LT06 Management Business F). The survey data indicates that, according to the experts, interdisciplinarity can better develop collaboration, appreciation to diversity in society and creativity skills while disciplinary approach mostly affects achievement orientation and disciplinary background. Limiting students' ability to adapt knowledge to real tasks was mentioned among top three characteristics of disciplinary learning.
Recommendation	The literature review findings suggest that to achieve the learning

outcomes and equip young generations with epistemology to handle arising challenges, **contemporary curricula should integrate scientific uncertainty**: "*Interestingly, when asked, no school age pupils were aware of reasons for climate change scientific uncertainty. Again, this may be a reflection of limited explanation of the subject in classroom environments, driven by curriculum, and with significant time and knowledge constraints. Having said this, it is important that a recognition of scientific uncertainty is incorporated into education activities, so that limitations of existing and future models can be appreciated*" (Reis and Ballinger, 2020:5).

To enable boundary crossing between disciplines, introducing philosophy (of science) as a compulsory discipline is seen as helpful by experts of the educational system as the interview findings suggest. It was perceived as a discipline that promotes broader views and enables interdisciplinarity: "*…epistemology is also very important, I think. And, you know, a basic, I think it's the generic discipline still philosophy. And I would make it a compulsory subject either at the end of school or the beginning of undergraduate. Everyone should do this philosophy at least*" (UK04 Education RPO M).

Interview data indicate that **informal education** organised by formalised educational institutions may contribute to developing skills, implying that a barrier may be turned to a boundary that can be crossed. Interviewees gave examples of informal initiatives and didactics such as challenge-based learning, pooling disciplines and teachers with different background for applying fundamental knowledge to practice and developing creative solutions through a hands-on case study. Collaboration between students and teachers, engagement of social partners and open schooling are seen as helpful tools by interviewees. They should allow students and/or staff to gain enough expertise to recognise the value and need of interdisciplinary study and work and develop skills needed for working life.

Interdisciplinary study groups suggested **design-thinking methodology** as a helpful tool to learn to embrace ambiguity (based on, e.g. IDEO approach). Together with accepting the risk, it is considered a strategic skill for leadership and for becoming a successful professional, which (should be re-)conceptualized as abilities to "*navigate the complexity of the society of acceleration and uncertainty*" (and not only to be a "high-performant").

	In addition, changes from disciplinary approach to e.g. STEM in teaching and respective reconfiguration of a learning space already at high school may be mutually reinforcing and contributing to the development of individual's freedom and group creativity: "*earlier they [high school students] would sit somewhat orderly in rows, now* [as STEM approach and a pilot textbook was introduced] *their desks are positioned creatively in the classroom as they wish because those textbooks allowed them to understand that they are free persons … and they start learning in the way that is comfortable to them*" (LT09 Engineering Business F).

Issue 5: SOCIAL INSENSITIVITY	**Disciplinary education is less socially sensitive**
Elaboration	Rote learning, standardised tests to monitor students' progress, academic achievements driven culture is criticised for failing to respond to the growing diversity. Socioeconomic background of students' families affects the choice of high school. Intersectionality of students' race, ethnicity, gender, disability and other social categories decrease chances of socially excluded or underrepresented groups to pursue education in science. Numerical targets as part of performance management at schools are criticised as a restriction of the curriculum for socio-economically or physically disadvantaged children's achievement (Thompson, 2017 as cited by Thompson, 2019). The pressures on schools to measure their students' achievements in recurring tests can affect young people's long-term cognitive development or emotional well-being (Thompson, 2019:5). Respectively allocated time to grade achievement undermines equity (NSW Office of the Minister et al., 1997:4 as cited by Hughes, 2019:5). Western science curriculum is criticised for little relevance to the local culture and environment as well as indigenous ways of knowing (Kerr et al., 2018:4). If educational institutions do not provide effective course counselling, including information about informal STEM activities, rigorous science curriculum "ethnic minority students' chances of pursuing STEM majors in college diminish" (Bicer and Capraro, 2019). Contrariwise, prior research has found that STEM curricula "narrow

	achievement gaps between students of different socioeconomic statuses, ethnicities, and genders" (Lee et al., 2019:1; Olson and Labov, 2014; Sanders, 2009; Yilmaz et al., 2010).
Empirical basis	As the educational systems in the studied contexts are still dominated by disciplinarity, some of the interviewees were suggesting that this knowledge organisation and respective structures at RPOs are gender-biased: "*I could think about a bit of like sort of … gender kind of barriers because we're talking about still a very kind of male dominated, kind of academic and political world. And I think about gender because we're not particularly advanced kind of society in terms of multi ethnicity and so on*" (IT06 Engineering, Business Administration, RPO and Policy-Making F). Some disciplines from social sciences are perceived as more responsive to diversity as they can include different topics such as gender equality into their curricula. Multicultural experience of teachers or researchers tends to make them more sensitive to diversity of students in the classroom. Also, currents challenges of migration that most European societies have faced, made interviewees more aware of language as a factor for achieving learning outcomes in science disciplines: "*I think that especially in a disciplinary teaching, because the courses are so full of things that you have to deal with, and … because of the language problems, … I should spend more time with the difficult words and to make sure that everybody understands what I'm talking about*" (FIN04 Meteorology School F). The surveys did not indicate that either the disciplinary or interdisciplinary approach better addresses socio-cultural characteristics of students. Rather, sensitivity to gender, race, language or engagement in science may be general (societal) culture dependent.
Recommendations	Literature suggests that underrepresented students' identity markers such as race, gender, socioeconomic status, disabilities, etc. are to be addressed by activities content, pedagogy, and purpose (Huang and Looi, 2020:21) to improve their academic achievement and further socialisation processes. **Curriculum differentiation**, rather than pedagogical differentiation, as an organisational response to the diversity

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	of students' abilities (Gamoran et al., 1995) may make different knowledge available for different groups of students (Oakes et al., 1992). Language checklists, which may also function as tools for increasing diversity responsiveness of the curricula, may be useful at university level education. Overall, terms used in different disciplines have to be defined and agreed upon by the community of learners and teachers.

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6. Framework and recommendations

Based on the evidence from part studies, the following framework for aligning science teaching and learning in formal educational contexts with the modus operandi of R&I (Figure 5) was designed. It outlines the issues and recommendations to deal with them.

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	• Developing 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

Figure 5. Framework for aligning science teaching and learning in formal educational contexts with the modus operandi of R&I

Respectively, the following **recommendations to the open schooling networks and the instruction designers** are formulated.

In creating open schooling networks and designing interdisciplinary experiences it is important to take care of:

a. Setting up the trading zone and designing a choreography to safely guide participants to "embrace the ambiguity of interdisciplinarity". This implies brainstorming and sharing, within the network, the conditions and the principles needed to set up a "creative and safe space where people are welcome to experiment themselves as boundary people". Positive emotional charge in a selected choreography is seen as a

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prerequisite for the sustainability of the trading zone. The spaces should also serve for coining a common language between different disciplines.

b. Unpacking the skills needed to accept the risk, embrace ambiguity and managing the equilibrium between the "*sense making and strange making skills*". This implies: i) selecting and brainstorming on, within the network, a bunch of interdisciplinary attitudes and skills, ii) designing activities to foster such attitudes and develop such skills, and iii) outlining specific learning outcomes and evaluation tools to measure their achievement.

c. Relating interdisciplinary experiences with the mindset of creating value to society in (although - uncertain) future, both as an individual characteristic and a criterion for evaluation of educational institutions performance. This aspect would serve as an element boosting science teachers and educational institutions' motivation to expand the network of and for open schooling.

To enact the changes for open-schooling and strengthen positive outcomes of interdisciplinary science education, **education policy makers/institutions should consider:**

a. Fostering the creation of - or the search for - locations and institutional contexts that can act as "third spaces", that is, spaces that do not belong to any disciplinary context but that are inhabited in safe and creative ways. These spaces should be suited to incorporate principles that can boost the activation of boundary crossing mechanisms and a system of acknowledgment for "boundary skills".

b. Promoting a cultural change in educational institutions aimed to overcome a "binary perspective" (either disciplines or interdisciplinarity) and to boost "embracing uncertainty, ambiguity, sense of belonging - not belonging", merging new professional identities that are based on interdisciplinarity. Structural support from policy making institutions for deconstructing the hegemony of sciences through revision of KPIs of institutional evaluation. It may facilitate constructing disciplinary professional discourses and attitudes which value differences in methodologies and outcomes.

c. Auditing organisational processes to detect gaps creating paradoxes and discouraging interdisciplinarity. In particular, human resource management practices such as recruitment and evaluation are of crucial importance to directing individuals or their groups to foster co-teaching, open schooling and collaboration between disciplines. Encouraging collaboration and collegiality in staff evaluation processes to promote interdisciplinarity could go hand in hand with promotion of responsible research and innovation culture at universities, a practice that is given importance by other projects (cf. Mejlgaard et al., 2020).

The findings from the 4 part studies also suggest **further research perspectives**:

a. The concept of the "trading zone" as a third space in education. Further research is needed to refine and outline a set of possible principles that can orient the design of a "choreography" that can safely guide participants to embrace the ambiguity of interdisciplinarity. The principles should be pointed out by developing both a literature review and by analysing the foreseen implementations through this lens.

b. The influences of interdisciplinary teaching and learning contexts or/and interdisciplinary methods on the meanings of professional identity. This enquiry could provide new insights into resources and trade-offs, suggest "important others" constructing self-images of present and prospective professionals.
c. The list of interdisciplinary skills and attitudes and their relationship with 21st century skills. Literature review highlighted the need for systematizing different categories of skills.
d. The findings from the part studies challenged the current operationalisation of futures thinking skills, which can further be explored both quantitively and qualitatively in relation to the construct of futures consciousness (Ahvenharju et al., 2018). The study groups pointed out lists of very promising skills and attitudes that are worth unpacking and further investigating. In particular, further research could unpack the skills needed to foresee and accept the risk, embrace ambiguity and manage the equilibrium between sense making and strange making skills. Furthermore, operational markers have to be pointed out to recognize and monitor the development of such skills.

The overall findings were summarized in a learning brief to be used for dissemination of WP1 results (see Annex 5, also available at the FEDORA project website: https://www.fedora-project.eu/recommendations/).

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Annexes

Annex 1. The final search string in literature review

(TITLE-ABS-KEY ((institutional OR conceptual OR professional OR social OR cultural) AND barriers AND science AND ("social innovation" OR rri))
OR TITLE-ABS-KEY ((institutional OR conceptual OR professional OR social OR cultural) AND barriers AND ("social innovation" OR rri))
OR ALL (anticipation AND skill AND "school education")
OR TITLE-ABS-KEY (anticipation AND skill AND school AND education)
OR TITLE-ABS-KEY (barriers AND science AND "social innovation")
OR TITLE-ABS-KEY ("school practices" AND "higher education")
OR TITLE-ABS-KEY (co-producers AND "scientific knowledge")
OR TITLE-ABS-KEY (criteria AND (designing OR revising) AND "teaching materials")
OR ALL (current AND "methods of science")
OR TITLE-ABS-KEY (current AND organization AND "formal education")
OR TITLE-ABS-KEY (deeper AND learning AND middle AND school AND science)
OR TITLE-ABS-KEY ("developing thinking skills")
OR TITLE-ABS-KEY ({disciplinary organization})
OR TITLE-ABS-KEY ("disciplinary paths")
OR TITLE-ABS-KEY (("disciplinary curriculum") OR ("interdisciplinary curriculum"))
OR TITLE-ABS-KEY ("diversity responsive" organization AND of AND knowledge)
OR TITLE-ABS-KEY ("emotional context" AND "science education")
OR TITLE-ABS-KEY ("formal contexts" AND "science education")
OR TITLE-ABS-KEY ("formal education" AND "science education")
OR TITLE-ABS-KEY ("formal education institutions")
OR TITLE-ABS-KEY (forms AND (co-teaching OR open-schooling))
OR TITLE-ABS-KEY ("diversity responsive")
OR TITLE-ABS-KEY (interdisciplinarity AND "school education")
OR TITLE-ABS-KEY (("disciplinary curriculum") OR ("interdisciplinary curriculum") AND education AND school)
OR TITLE-ABS-KEY (interdisciplinary AND multidisciplinary AND transdisciplinary AND education)
OR TITLE-ABS-KEY (transdisciplinarity AND schools AND education)
OR TITLE-ABS-KEY ("knowledge gain" AND disciplines)
OR TITLE-ABS-KEY ("knowledge organization" AND ((new AND forms) OR barriers))
OR TITLE-ABS-KEY (new AND modus AND operandi AND of AND science)
OR TITLE-ABS-KEY ("new skills" AND ("school education" OR (university AND education)))
OR TITLE-ABS-KEY (education AND skills AND {A generation})
OR TITLE-ABS-KEY ({organisation of knowledge} AND science)
OR TITLE-ABS-KEY ({organisation of knowledge} OR {production of knowledge} AND education AND science)
OR TITLE-ABS-KEY ("organisation of knowledge" and schools)
OR TITLE-ABS-KEY ("disciplinary organization" AND education)
OR TITLE-ABS-KEY (school AND education AND "societal changes")
OR TITLE-ABS-KEY (prepare AND children AND societal AND changes)
OR TITLE-ABS-KEY ({disciplinary formation})
OR TITLE-ABS-KEY ("reflection skill" AND school AND education)

OR TITLE-ABS-KEY ("role of science" AND school AND practices)
OR TITLE-ABS-KEY ("science education models")
OR TITLE-ABS-KEY ({science curriculum} AND "school education")
OR ALL("social emotional learning in schools")
OR TITLE-ABS-KEY (({social learning} OR {emotional learning}) AND "school education")
OR TITLE-ABS-KEY ({society of acceleration} OR "acceleration society")
OR TITLE-ABS-KEY ({STEAM school})
OR TITLE-ABS-KEY (steam AND education AND future AND skills)
OR TITLE-ABS-KEY ("STEM school")
OR TITLE-ABS-KEY ({thinking skills} AND school AND {scientific knowledge})
OR TITLE-ABS-KEY ("thinking skills" AND "school education")
OR TITLE-ABS-KEY (skills AND contemporary AND challenges AND school AND education)
OR TITLE-ABS-KEY (future-scaffolding AND skills)
OR TITLE-ABS-KEY (future AND scaffolding AND skills AND school))
AND PUBYEAR > 2009 AND (LIMIT-TO (LANGUAGE,"English")) AND SUBJAREA(ARTS OR BUSI OR DECI OR ECON OR PSYC OR SOCI)

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Annex 2. Interview protocol

The questionnaire to representatives of **research performing organisations**

Participant information for the interviewer: participant data from the sampling frame (institution, position other criteria of selection, name, surname, e-mail/phone or other publicly available information)
Introduction to interview
Dear participant of the interview, Thank you for agreeing to take part in the research project *Future-oriented Science EDucation to enhance Responsibility and engagement in the society of Acceleration and uncertainty* (FEDORA, www.fedora-project.eu). Our project, among other important goals, seeks to collect opinions of experts on potential and limits of disciplinary forms of organizing knowledge in schools and universities. The project is funded by the European Commission's Horizon2020 programme (grant agreement No. 872841, coordinated by the University of Bologna, Italy), and this part of research is carried out by Kaunas University of Technology, Lithuania. In this study we use the term 'discipline-based approach' which means not only discipline-based curriculum and teaching, but also all other aspects in education such as research and its funding or organisation management. In this interview, we would like you to think about the potential and limits of the discipline-based approach as opposed to the interdisciplinary one. We are aware that both disciplinary and interdisciplinary approaches have their merits and shortcomings, but our goal is to know your first-hand experiences, contents and discontents with the discipline-based approach in schools and universities. If any questions arise at any stage of the interview, please direct them to dr. Raminta Pučėtaitė (raminta.pucetaite@ktu.lt), PI of this work package. TO INTERVIEWER: Aspects of discipline-based organisation of knowledge from literature review: pay system, internal institutional design (organisation into departments, funding based on departments/teaching subjects, management functions and standard operations oriented to departmental system), discipline-based approach to teacher preparation, logic of national level funding, national/subnational system of institutions, even the nature of knowledge in disciplines itself.

Question basis	Qualitative interview question
1.Getting to know the interviewee's experience with disciplinarity vs interdisciplinarity	
Comment to the INTERVIEWER: Information about personal experience will help us in the data analysis. It makes a difference whether the interviewee has just general views on interdisciplinarity vs experience. This question may be skipped if a representative of the University governance is interviewed. **Could you tell me briefly what experience you have in teaching approaches or applying certain research methods? Are they more discipline-based or interdisciplinary (also multidisciplinary)?**	
I. Current discipline-based organisation of knowledge	
Potential and limits	

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What potential and limits of the disciplinary organisation are perceived, observed or recognised by the various stakeholders involved in R&I, education, policy, entrepreneurial realm (FEDORA proposal, p. 10)? How multiple stakeholders evaluate the current organisation of knowledge in disciplines in the formal education institutions (universities and schools) (FEDORA proposal, p. 16)?	1. *Curriculum level:* Let us start from probably the most obvious or better-known aspect of education in universities – discipline-based teaching. **In your opinion, what is a predominant education model in universities in [COUNTRY] - disciplinary or interdisciplinary (or other type)? Why is it so?** Let us focus on discipline-based teaching now. *1.1. Merits:* **In your opinion, what are the merits of a discipline-based teaching?** **In your opinion, has such a discipline-based teaching achieved the expected outcomes of national education?** *1.2. Shortcomings:* **In your opinion, what are [other] shortcomings of such a discipline-based teaching?** *Prompt:* Students' skills *Prompt:* Employers/markets' needs *Prompt:* Multi teaching, inter-department collaboration possibilities *2. Organisational design:* Discipline-based organisation of research performing institutions gives clarity in functions and responsibilities and helps University management to monitor performance results of discipline-based divisions, on the one hand. On the other hand, discipline-based division into departments and resulting rigid HRM practices (such as remuneration, employee evaluation), (re)distribution of financial resources at Universities has received criticism for undermining interdisciplinary teamwork. *2.1. Merits* **In your opinion, what are the merits of discipline-based organisational designs?** *2.2. Shortcomings* **Do you see any shortcomings of the discipline-based operations?**

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	Prompt: teamwork in projects 3. *Cultural "layers"/subcultures:* **To what extent are universities in [COUNTRY] prepared to embrace the interdisciplinary approach to teaching, research and overall functioning? You can use your university as an example.** *Prompt / rephrase of the question:* in some countries experts identify the culture of closed "disciplinary clubs" at universities which resists new approaches in education and organisational design. What is your view about the situation in [COUNTRY]? 4. *Research and research funding:* Now I would like you to think about research in universities in [COUNTRY] that you are familiar with. **How is research in [COUNTRY] universities conducted? Is it more discipline-based or interdisciplinary? Why?** *Prompt*: May choose a specific university as a case example Again, I would like you to specifically reflect on discipline-based research. **What are the merits of discipline-based research? What about shortcomings?** *Prompt*: May choose a specific university *Prompt if not answered:* Do you have some specific discontents with the current approach to research? **Also, with regard to research funding policies and practices would you say the research funding goes along disciplinary lines in [COUNTRY] universities? Why?** **As an expert, what pros and cons would you like to highlight in current research funding in [COUNTRY]?** *Prompt*: Capacities
Skills formed by disciplinary organisation of knowledge	

What potential and limits they see when preparing the young to face the societal changes: what skills are formed; what new skills are needed to grapple with the contemporary challenges which science education should form; what "old" skills the young are losing, etc (FEDORA proposal, p. 16).	*5. 21st century skills* 21st century skills that are and presumably will be needed in the future society are an important guideline for educators. These skills encompass various life, learning, information skills, etc. In addition, experts highlight future-thinking skills such as anticipation, foresight, risk taking, scenarios building, probabilistic reasoning as important to grapple with the contemporary challenges. **In your opinion, how does discipline-based approach help or inhibit development of the mentioned skills?**
Diversity responsiveness	
If and how the current organisation is diversity-responsive (FEDORA proposal, p. 16)?	*6. Diversity responsiveness* Education experts also highlight the importance of embracing diversity in education system. **In your opinion, how does discipline-based teaching in [COUNTRY] respond to student and staff diversity (in terms of gender, race, ethnicity, socioeconomic background etc)?** *Prompt:* Do you have any experiences that support or contradict the view that discipline-based teaching sufficiently responds to diversity? *Prompt*: what are your views on few e.g. women entering science disciplines? *Prompt*: what topics do we select for problem-based teaching, examples we use in experiments on natural science or engineering disciplines? *Prompt:* language and cultural challenges when communicating science to immigrant students? *To INTERVIEWER: If the interviewee does not see the situation as problematic or cannot relate discipline-based teaching to diversity-responsiveness, proceed to next block of questions.* **Can and how can discipline-based teaching achieve better diversity responsiveness?**
Resulting barriers to science, social innovation and RRI	

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What institutional, conceptual, professional, social and cultural barriers to science and social innovation and to RRI can be ascribed to the current organisation of formal education into disciplinary paths (FEDORA proposal, p. 10)?	*7. Barriers to science, social innovation and RRI* A trending discourse in science highlights responsible research and innovation (RRI), as well as social innovation. However, there's a concern among education experts that discipline-based teaching and research raise many barriers to promotion of social innovation and responsible research and innovation. 7.1. **Do you see any particular institutional and / or socio-cultural barriers to social innovation or responsible research and innovation due to discipline-based teaching?** **What about research? Do you perceive any institutional and / or cultural barriers to social innovation and RRI due to the discipline-based approach in research?** *To INTERVIEWER:* *Social innovation is the process of developing and deploying effective solutions to challenging and often systemic social and environmental issues in support of social progress.* *'Responsible research and innovation' usually means seeking to align technological innovation with broader social values, to produce ethically acceptable, sustainable and socially desirable research and innovation outcomes (https://www.rri-practice.eu/about-rri-practice/what-is-rri/)*
How can the universities and schools be supported in order to break down the barriers and, at the same time, to exploit the potential of a disciplinary formation? (FEDORA proposal, p. 10) What are institutional, conceptual, social, professional, epistemological and cultural barriers to science and social innovation induced by a vertical disciplinary organisation (the "silos" and "skill gap" effects) and how to break them down (SO1, FEDORA proposal, p. 5)?	*7.2. Ways to break down the barriers, exploit the potential of disciplinary organisation of knowledge* **How can universities break down the institutional and cultural barriers posed by discipline-based organisation of knowledge to social innovation and responsible research and innovation? What culture and skills are needed?** **How could universities exploit the potential of the discipline-based organisation of knowledge in creating social innovation and responsible research and innovation?**
II. Other forms of knowledge organisation	

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What other forms of knowledge organisation can be elaborated with the potential to develop thinking skills needed to grapple with the new modus operandi of science and play an active role (as co-producers and/or users of scientific knowledge) in the society of acceleration? (FEDORA proposal, p. 10) Compare different disciplinary, inter-multi-transdisciplinary forms of knowledge organisation in terms of their limits and potentialities to develop, in the young generation, inter-multi-transdisciplinary thinking skills needed to grapple with the new methods and features of R&I and play an active role (as co-producers and/or users of scientific knowledge) in the society of acceleration (SO2, FEDORA proposal, p. 5).	*8. Suggestions for other approaches* **Other than discipline-based approaches, what other approaches to teaching/researching/institutional design should be promoted? Why?** If a university management person is interviewed: **How does your university integrate other approaches? OR How is your university preparing to integrate other approaches?**
III. End of the interview	
	The project team would like to invite you to take part in other research activities. If you are interested to be involved in a study group, focus group or just stay informed on the progress, please choose one or more of the options: 1. I am interested to be involved in an international study group (Yes/No) 2. I am interested to be involved in a national study group (Yes/No) 3. I am interested to participate in a focus group (group discussion) (Yes/No) 4. I am interested to be informed on the progress of the FEDORA project. (Yes/No) *To interviewer:* • *If at least one yes, ask for permission to contact; ask to choose a method of contacting*

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Annex 3. Characteristics of the interviewees

No	Interviewee code	Disciplinary background	Type of represented organisation	Position(s)	Gender
1.	IT01	Mathematics	School	Teacher, researcher, teacher trainer	F
2.	IT02	Information sciences	Business	Data and info designer	F
3.	IT03	Physics	School	Teacher	F
4.	IT04	Science Education, Physics	School and policy maker	Researcher, expert, teacher	F
5.	IT05	Mathematics	RPO	President	F
6.	IT06	Engineering, Business administration	RPO and policy maker	Scientific manager	F
7.	IT07	Philosophy and law	RPO	University government, researcher	M
8.	IT08	Mathematics	RPO	Teacher training	M
9.	IT09	Physics	RPO	Researcher, RDI manager	M
10.	FIN01	Mathematics	RPO	Researcher, University government	M
11.	FIN02		RFO	Manager	F
12.	FIN03	Physics	RPO	University government, researcher	M
13.	FIN04	Meteorology	School	Teacher	F
14.	FIN05		Business	CEO, PhD in management of technological innovations	M
15.	FIN06	Biology	RPO	University government	F
16.	LT01	Chemistry	RPO, School	Head of department, researcher, school teacher	M
17.	LT02	Sociology	RPO	Researcher, university government	F
18.	LT03	Education	School	Principal, PhD in education sciences	F
19.	LT04	Mathematics	RPO	University government, prior experience in business	M
20.	LT05	Education	RPO	University government, teacher	F
21.	LT06	Management	Business	HR manager	F
22.	LT07	Economics	RFO and RPO	Member of the social	F

				sciences and humanities board, Dean	
23.	LT08	Physics	School, RPO	Teacher, doctoral student	F
24.	LT09	Engineering	Business	HRM manager	F
25.	UK01	Social sciences and humanities	RPO	Researcher, administrative duties	M
26.	UK02		School	Science teacher, former curriculum leader	F
27.	UK03	Social sciences	RFO	Deputy team head	F
28.	UK04	Education	RPO	Director of an institutional research funding programme	M
29.	UK05	Social sciences	RPO	Associate head of research programmes, researcher	F
30.	UK06	History, Politics	Business	Venture manager	M

Annex 4. Survey questionnaires

4a Students' questionnaire

To proceed, we should know whether you study at high school or university. Please tick a respective box:

a. I am a high school student
b. I am a university student

I. Sociodemographic data

1. Your age: *write a number of full years at the moment*
2. Gender:
a) Male
b) Female
c) Non-binary
d) Prefer not to say
3. In which country do you study? – *drop-down menu*
   a. Finland
   b. Italy
   c. Lithuania
   d. Netherlands
   e. UK
4. *To high school students:* What type of high school do you attend?
   To university students: what type of high school did you attend?
   a. lyceum
   b. gymnasium
   c. comprehensive ("vidurinė")
   d. academy or free school
   e. grammar school
   f. further education college
   g. high school without emphasis on natural sciences ("lukio")
   h. high school with emphasis on natural sciences ("erikoislukio")
   i. international Baccalaureate school or similar
5. Where is the high school you attend/-ed situated?
   a. A big city
   b. The suburbs or outskirts of a big city
   c. A town / small city
   d. A country village
6. *To both type students*: Is the language in which you study the same as the one you use at home:
   a. Yes
   b. No

To University students: Was the language in which you studied at high school the same as the one you use at home?

a. Yes
b. No

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II. Experience with the interdisciplinarity

7. What is your experience with interdisciplinary learning (i.e. when you studied something using a combination of disciplines, e.g. math, arts, sociology)? Please tick a respective option that applies to your experience. *Each answer is followed by yes/no/don't know.*
   a) All courses at school are/were organised in that way (e.g. STEM or STEAM model is/was applied)
   b) I regularly participate/-ed in extracurricular activities that have/had an interdisciplinary approach to science learning (*if so, an extra Q*: did you choose these activities yourself? yes/no)
   c) I participate/-ed in short-term interdisciplinary projects on science (science fairs, workshops, summer camps etc.)
   d) Other: *write in*

8. To both type students: When learning science (e.g. physics, math, chemistry etc.) at high school, how often do / did the following activities occur?
   To University students: When learning at University, how often do the following activities occur?
   Matrix with a Likert Scale 1-5: 1 never, 2- seldom (e.g. 1-2 times a year), 3-often (e.g. once every 2-3 months), 4-very often (e.g. once a month), 5- almost every day, 6 - I don't know
   a. I am/ was given opportunities to explain my ideas.
   b. I spend/spent time solving real life problems.
   c. I am/ was required to argue about scientific questions.
   d. I am/ was asked to draw conclusions from research I conducted.
   e. One or more teachers explain(s)/explained how a scientific theory (concept, idea) can be applied to a number of different phenomena (e.g. the movement of objects, substances with similar properties).
   f. I am/ was allowed to design my own research projects.
   g. There is/was a class debate about scientific issues.
   h. One or more teachers clearly explain(s)/explained the relevance of a scientific theory (concepts) to our lives.
   i. I am/ was asked to perform research to test ideas.
   j. My teachers were/are typically able to answer my science questions.
   k. When I had difficulty understanding a science concept, my teachers allocated extra time to explain it to me.
   l. When I feel/felt at a loss when studying science, my teachers emotionally encourage/d me.
   m. When learning science, my teachers usually welcome/d students' questions.
   n. Professionals outside school are/were invited to classes as guest speakers.
   o. Certain classes/ courses at school/university are/were taught by several teachers from different disciplines.
9. What classes/courses are/were you taught by several teachers? *Write in*

10. To what extent the following statements characterize you? *Scale: 1-not at all true of me to 5 - very true of me, 6 - i don't know*
    a. I understand science concepts well enough to explain phenomena happening around me.
    b. I am certain that science can solve real life problems.

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c. Compared with other students in science classes/courses I expect to do well.
d. I'm certain I can understand the ideas taught in science classes/courses.
e. I expect to do very well in science classes/courses.
f. Compared with others in science classes/courses, I think I'm a good student.
g. I am sure I can do an excellent job on the problems and tasks assigned for science classes/courses.
h. I think I will receive a good grade in science classes/courses.
i. My study skills are excellent compared with others in science classes/courses.
j. Compared with other students in science classes/courses I think I know a great deal about the subjects.
k. I know that I will be able to learn the material for science classes/courses.

11. To what extent do you disagree or agree with the statements related to studying science? *1-5 Likert scale 6 - i don't know*
    a. I generally have fun when I am learning science topics.
    b. I like reading about science.
    c. I am happy working on science topics.
    d. I enjoy acquiring new knowledge in science topics.
    e. I am interested in learning about science topics.
    f. I feel that science is relevant to me as a citizen.
    g. I feel that scientific knowledge enables me to deal with complexity of societal arrangements.
12. What do you think you will be doing 5 years from now?
    a. I will be working because the occupation I want does not require a study degree (e.g., diploma or university degree). *High school students only*
    b. I will be working because I need to be financially independent. *Both types students*
    c. I will be studying because I do not know what I would like to do yet. *Both types students*
    d. I will be studying because the occupation I want requires an advanced study degree (e.g., Master [diploma or university – high school students] degree). *Both types students*
    e. I will be doing voluntary or civil service because I want to help society. *Both types students*
    f. I will be influencing and organizing a movement for social or environmental causes. *Both types students*
    g. I will be doing something else. - *Write in.*
13. To what extent do you agree with the following statements? *5-item Likert: 1 = "disagree strongly"; 5 = "strongly agree"*
    a. I think about the consequences before I do something.
    b. I think about how things might be in the future.
    c. I think often about what tomorrow will bring.
    d. I believe I can succeed at most any endeavor to which I set my mind.
    e. I hardly ever expect things to go my way. (R)
    f. I rarely count on good things happening to me. (R)
    g. I am usually able to protect my personal interests.
    h. I feel like what happens in my life is mostly determined by powerful people. (R)
    i. I often use new ideas to shape (modify) the way I do things
    j. I am often on the lookout for new ideas.

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k. I often re-evaluate my experiences so that I can learn from them.
l. I find it boring to discuss philosophy. (R)
m. I think that all the Earth's systems, from the climate to the economy, are interconnected.
n. I have had the experience of feeling "at one" with nature.
o. At least one time in my life, I have felt united with nature.
p. I show concern and care for peers.
q. I believe in being loyal to all mankind.
r. When they are in need, I want to help people all over the world.
s. Universalism (that is, broad-mindedness, beauty of nature and arts, social justice, a world at peace, equality, wisdom, unity with nature, and environmental protection) is an important life-guiding principle for me.
t. Benevolence (that is, helpfulness, honesty, forgiveness, loyalty, and responsibility) is an important life-guiding principle for me.

14. *To university students only:* At graduation of high school you knew what you want to study further:
    a. Yes
    b. No
15. *To university students only:* What is the title of your study programme?: *Write in*
16. What kind of job do you expect to have when you are about 30 years old? *Write in*
17. How important are the following things in the decisions you make about your future occupation? Likert 1 – not important at all, 5 – very important, 6 - i don't know
    a. My parents' or guardians' expectations about my occupation.
    b. The plans my close friends' have for their future.
    c. What industry representatives / experts say;
    d. What influencers/bloggers say
    e. My natural talents/inclinations;
    f. My deep interest;
    g. My good achievements at school;

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4b Experts' questionnaire

To proceed, we must know what your professional field is. Please tick a respective box. Currently, you are a…

a. High school teacher
b. High school principal
c. Policy maker (e.g. ministry, city council)
d. Policy implementer (e.g. study quality assurance institution, education department at municipality)
e. Other *write in*

To teachers only: You teach…

a. science subjects (e.g. math, physics, chemistry, biology)
b. other subjects *please write in*

I. Sociodemographic data

2. Your age: *write a number of full years at the moment*
3. Gender:
   a) Male
   b) Female
   c) Non-binary
   d) Prefer not to say
4. *Teachers only:* What subject(s) do you teach? *Write in*
5. In which country do you work? – *drop-down menu*
   a. Finland
   b. Italy
   c. Lithuania
   d. Netherlands
   e. UK

II. Experience with the interdisciplinarity

6. What is your experience with interdisciplinary/ cross-subject education? Tick the respective options which are relevant to your experience. *Answer options: yes/no/n.a.*
   a) I have experience of co-teaching an interdisciplinary course with other teachers (*if yes, go to Q7*)
   b) I have organized an interdisciplinary science event (*if yes, go to Q7 all the other choices below go to Q8*)
   c) I have participated in professional development activities on STEM or STEAM model
   d) I have participated in the processes of implementing STEM or STEAM model at school(s)
   e) I have cooperated with different institutions (e.g. government or NGOs) to encourage girls or socially disadvantaged children to pursue career in science
   f) I have participated in a national (ministry-level) working group developing or/and elaborating on STEM or STEAM framework at schools
   g) I have prepared policy/-ies for designing and/or implementing STEM or STEAM model at schools

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h) I have assessed the effectiveness (quality, outcomes) of STEAM or STEM model at school(s)
i) Other: *write in*

7. *for those who gave positive answers to 6b:* What is the title of the course/event? *Write in*

8. *to teachers*: How often do the following activities occur in your teaching?
   to the other groups of respondents: Please indicate how often, in your opinion, the following occurs in science lessons.
   Matrix with a Likert Scale 1-5: 1 never, 2- seldom (e.g. 1-2 times a year), 3-often (e.g. once every 2-3 months), 4-very often (e.g. once a month), 5- almost every day, 6 - don't know
   a. Students are given opportunities to explain their ideas.
   b. Students spend time solving real life problems.
   c. Students are required to argue about scientific/science questions.
   d. Students are asked to draw conclusions from research they conducted.
   e. Teachers/I explain how a scientific theory (concept, idea) can be applied to a number of different phenomena (e.g. the movement of objects, substances with similar properties).
   f. Students are allowed to design their own research projects.
   g. There is a class debate about scientific research.
   h. Teachers clearly explain the relevance of a scientific theory (concepts) to students' lives.
   i. Students are asked to perform research to test ideas.
   j. Teachers/I are/am typically able to answer students' science questions.
   k. When a student has difficulty understanding a science concept, teachers/I allocate extra time to explain it to her.
   l. When students feel at a loss when studying science, teachers emotionally encourage them.
   m. When teaching science, teachers/I usually welcome students‘ questions.
   n. When teaching science, teachers/I rely on arts-based resources (e.g. films, media, visual arts).
   o. When teaching science subjects, teachers/I relate the contents with other subjects.
   p. Professionals outside school are invited to classes as guest speakers.
   q. In science classes students are encouraged to reflect on potential consequences of research and innovation.

9. To what extent do you disagree or agree with the following statements? *1-5 Likert, 6 - I don't know*

   a. *To teachers only*: I understand science concepts well enough to explain phenomena happening around us to students.
      To the others: Teachers understand science concepts well enough to explain phenomena happening around us to students
   b. I believe that scientific knowledge can be used to solve societal or / and environmental problems.

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10. In your opinion, to what extent the following statements apply to single-subject/disciplinary vs cross-subject/interdisciplinary approach to science education? *1-5 Likert scale as a continuum*:
1 Much more characteristic to single-subject/disciplinary education; 2 somehow more characteristic to single-subject/disciplinary education; 3 equally characteristic to single-subject/disciplinary and cross-subject/ interdisciplinary education; 4 somehow more characteristic to cross-subject/ interdisciplinary education; 5 much more characteristic to cross-subject/interdisciplinary education

    a. It is the basis of high school education
    b. It creates knowledge advantage to students
    c. It helps teachers to capture students' talents
    d. It limits students' ability to adapt knowledge to real tasks
    e. It allows to deeply reflect impacts of the subject matter on society
    f. It enables real breakthrough
    g. It creates skills advantage to students
    h. It creates social networking advantage to students
    i. It strengthens students' skills to act in public interest
    j. It promotes teachers' self-efficacy
    k. It improves teachers' social skills (e.g. networking, teamworking)
    l. It broadens teachers' knowledge about the topic
    m. It opens up opportunities for diverse methods of teaching/learning (working)
    n. It gives more opportunities to capture advantages of diversity of a students' group
    o. It facilitates growth of students as personalities
    p. It increases institutional resilience
    q. It increases national resilience
    r. It is emotionally engaging for both teachers and students
    s. It gives just superficial knowledge
    t. It challenges teachers' scientific identity
    u. It challenges the ways in which work at schools is organized
    v. It requires too many administrative efforts to redesign work patterns
    w. It demands additional efforts for teachers' preparation and development
    x. It allows for specific feedback
    y. It helps students to perceive the interrelations between phenomena constituting the complexity of societal arrangements
    z. It favours teachers' career progress

11. In your opinion, what are (social, institutional or individual) barriers to cross-subject/interdisciplinary teaching (e.g. using STEM or STEAM models)? *write in*
12. In your opinion, to what extent the following outcomes are characteristic of single-subject/disciplinary vs cross-subject/interdisciplinary approach to science education?
1-5 Likert scale: 1 Much more characteristic to single-subject/disciplinary education; 2 somehow more characteristic to single-subject/disciplinary education; 3 equally characteristic to single-subject/disciplinary and cross-subject/ interdisciplinary education; 4 somehow more characteristic to cross-subject/ interdisciplinary education; 5 much more characteristic to cross-subject/interdisciplinary education
    a. Academic achievement
    a. Employability skills

b. Creativity skills
c. Problem solving skills
d. Leadership skills
e. Collaboration skills
f. Career orientation
g. Self-regulation
h. Self-efficacy (i.e. the belief in one's capabilities to organize and execute the courses of action required to manage prospective situations)
i. Personal identity
j. Scientific identity (e.g. students identify themselves with a certain scientific discipline)
k. Futures consciousness (i.e. students taking time perspective, agency beliefs, openness to alternatives, systems perception and concern for others)
l. Sustainability skills (e.g. valuing sustainability, supporting fairness, promoting nature, problem framing, collective action etc.)
m. Affective engagement with disciplines
n. Appreciation of diversity in society
o. Participation in public decision making
p. Other *write in*

13. *To teachers only*: To what extent do you address the following values in your teaching practice? 1-5 Likert scale
    a. trust
    b. social (in)equality
    c. fairness
    d. human/animal rights
    e. tolerance
    f. ecology
    g. other *write in*
14. *To teachers only*: In your teaching experience, which of the students‘ needs in learning practice have you faced?
    a. linguistic
    b. financial
    c. gender-based
    d. digital skills
    e. emotional
    f. other *write in*
15. Which of the perspectives below do you most agree with?
    a. Cross-subject/Interdisciplinary approach to science teaching at primary schools should be more --- less promoted --- stay at the scope as it is
    b. Cross-subject/Interdisciplinary approach to science teaching at secondary and high schools should be more --- less promoted --- stay at the scope as it is
    c. Cross-subject/Interdisciplinary approach to science teaching at higher (tertiary) education should be more --- less promoted --- stay at the scope as it is

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Annex 5. Learning brief of interdisciplinarity

Recommendations

Key recommendations to Open Schooling networks and instruction designers

1. Setting up a safe and emotionally positive trading zone

2. Designing a methodology to facilitate embracing the ambiguity of interdisciplinarity

3. Developing the skills needed to accept the risk and manage the equilibrium between sense-making and strange-making skills in a common coined language

4. Relating interdisciplinary experiences with value to society

Key recommendations to policymakers and institutions

1. Fostering the creation of locations and institutional contexts that can act as spaces that do not belong to any disciplinary context

2. Promoting a cultural change in educational institutions aimed to overcome a "binary perspective" (disciplinarity vs interdisciplinarity)

3. Merging new professional identities that are based on interdisciplinarity

4. Auditing organisational processes, in particular, human resource management practices to detect the gaps that create paradoxes and discourage interdisciplinarity

Get inspired, learn more, and expand your views!

IDENTITIES PROJECT www.identitiesproject.eu
VIDEO https://www.youtube.com/watch?v=qDiGoRpfxuk

Akkerman, S. F., & Bakker, A. (2011). Boundary crossing and boundary objects. *Review of educational research*, 81(2), 132-169.

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

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FEDORA LEARNING BRIEF
on new inter-multi-trans-disciplinary forms of knowledge organization for co-teaching and open-schooling

FEDORA

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.

Artificial intelligence, quantum technologies, climatology, and data science are examples of emerging interdisciplinary fields of crucial societal relevance that question disciplinary-based teaching.

How to address this misalignment is one of FEDORA's objectives.

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?

These questions have been investigated through a literature review, cross-national interviews with STEM professionals, interdisciplinary study groups and cross-national surveys with students.

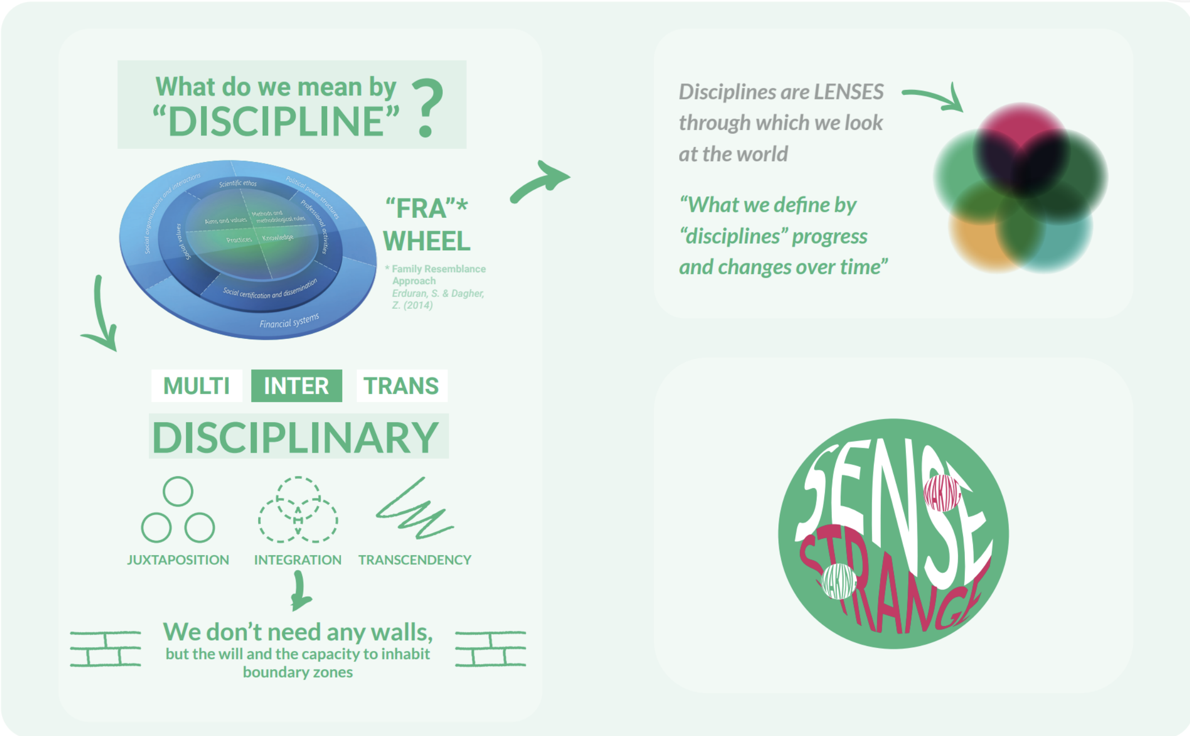
The dominance of disciplinarity in schools and universities curricula creates science identity, deep knowledge of a subject and technical expertise, which is essential for team working in a professional field.

Yet, to meet the challenges of the future and deal with growing social diversity at work and uncertainty, we need transferable skills such as applying conceptual knowledge to practical problem-solving, self-confidence and efficacy, leadership, life-long learning, futures thinking skills etc., which the disciplinary approach fails to develop.

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 both 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.

On boundary crossing in interdisciplinarity



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