IDENTITIES

Enlightening
Interdisciplinarity
in STEM
for Teaching

"The IDENTITIES Project: an overview"

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Co-funded by the
Erasmus+ Programme
of the European Union
Grant Agreement n°2019-1-IT02-KA203-063184

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Integrate Disciplines to Elaborate Novel Teaching approaches to InTerdisciplinarity and Innovate pre-service teacher Education for STEM challenges

KA203 - STRATEGIC PARTNERSHIP FOR HIGHER EDUCATION

STRATEGIC PARTNERSHIP: 5 UNIVERSITIES

ALMA MATER STUDIORUM - UNIVERSITA' DI BOLOGNA (COORDINATOR)

UNIVERSITA' DI PARMA

PANEPISTIMIO KRITIS

UNIVERSITAT DE BARCELONA

UNIVERSITE DE MONTPELLIER

Project Duration: 01-09-2019 - 31-08-2022 (36 months)

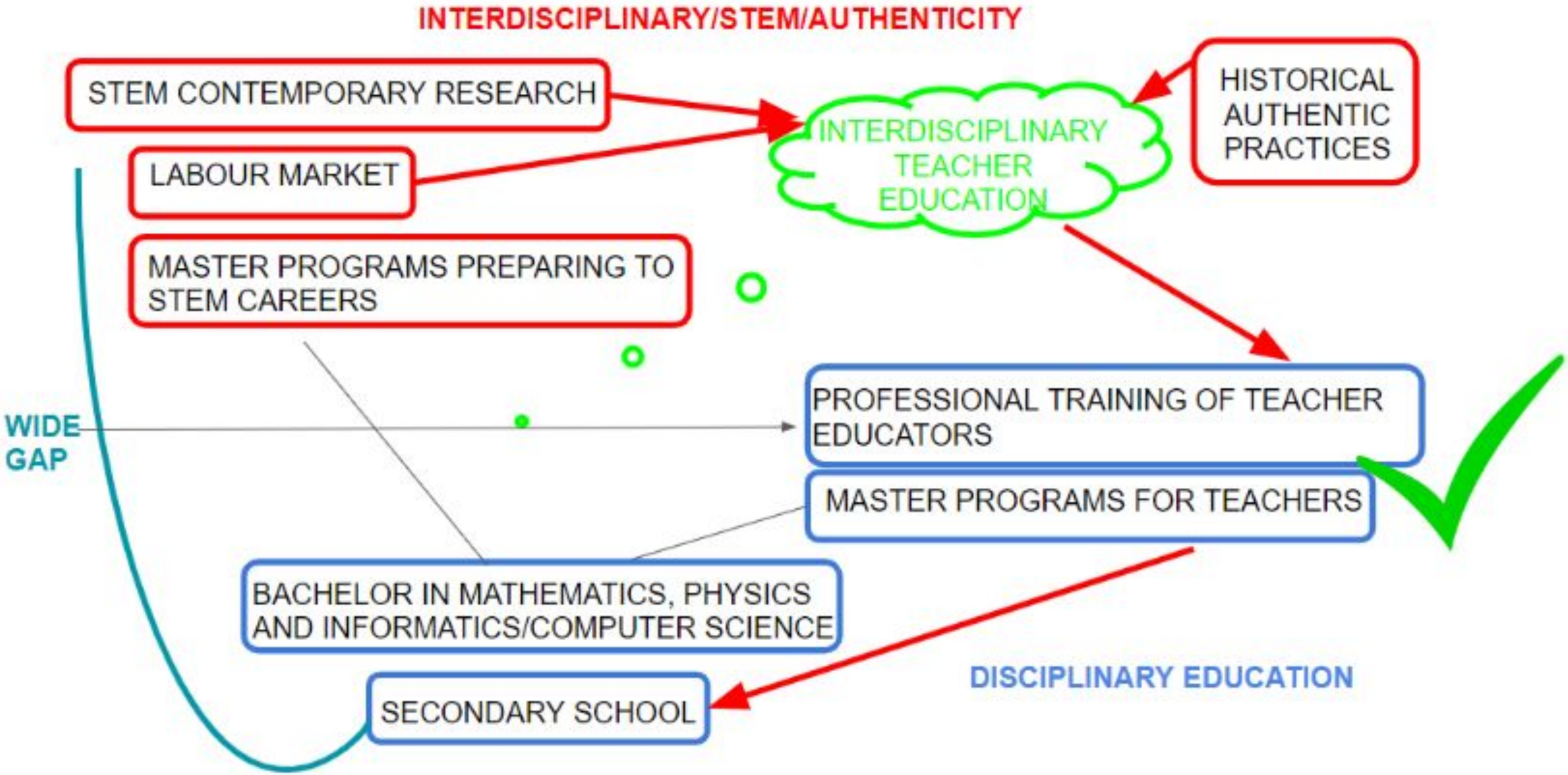
Erasmus+ project goals:

Supporting individuals in acquiring and developing basic skills and key competences

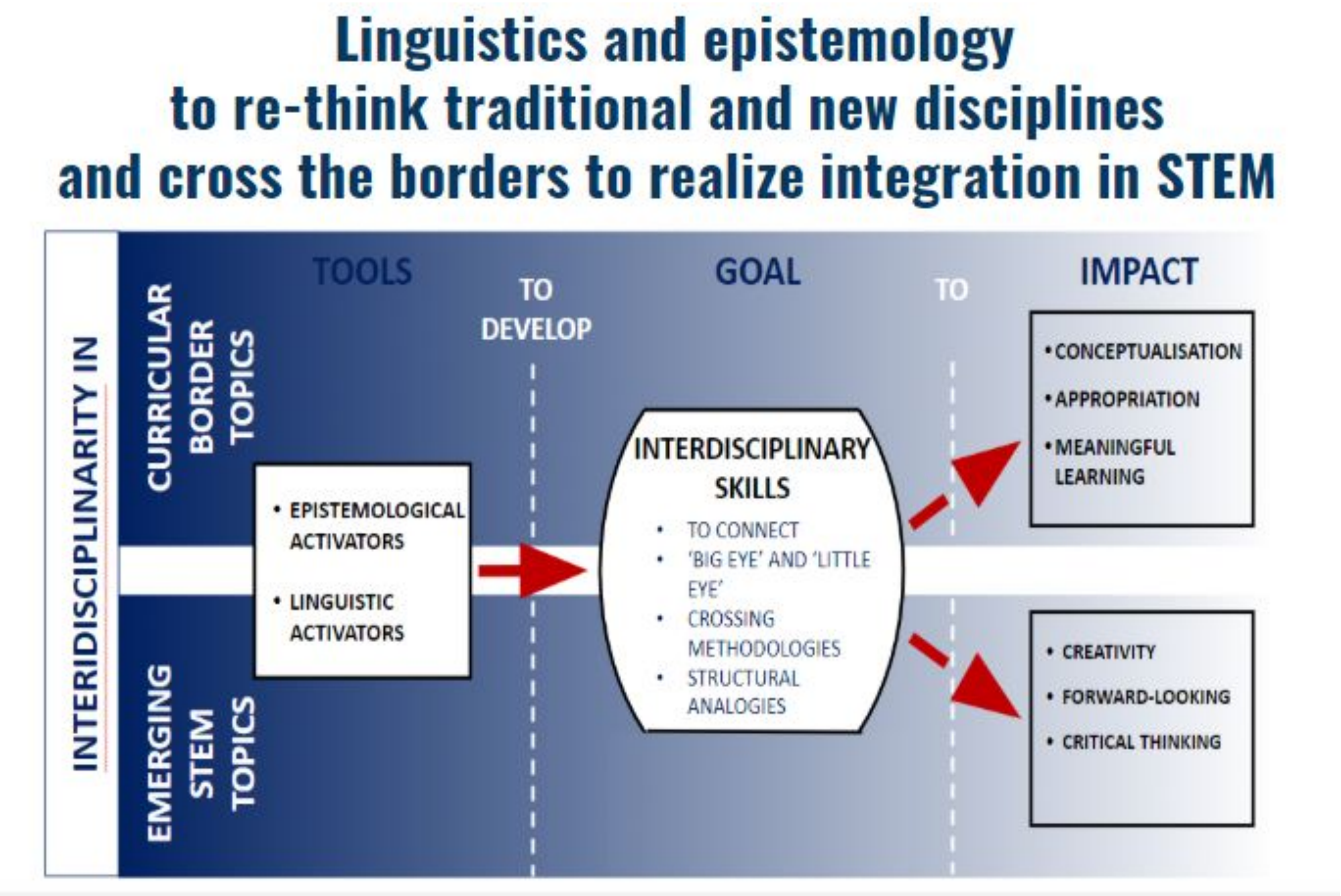
New innovative educational methods/development of training courses

Overcoming skills mismatches (basic/transversal)

> Preservice interdisciplinary teacher education as KEY ACTION to overcome didactical traditions



Key ideas



Linguistics and epistemology
to re-think traditional and new disciplines
and cross the borders to realize integration in STEM
INTERIDISCIPLINARITY IN
CURRICULAR BORDER TOPICS
EMERGING STEM TOPICS
TOOLS
• EPISTEMOLOGICAL ACTIVATORS
• LINGUISTIC ACTIVATORS
TO DEVELOP
GOAL
INTERDISCIPLINARY SKILLS
• TO CONNECT
• 'BIG EYE' AND 'LITTLE EYE'
• CROSSING METHODOLOGIES
• STRUCTURAL ANALOGIES
TO
IMPACT
• CONCEPTUALISATION
• APPROPRIATION
• MEANINGFUL LEARNING
• CREATIVITY
• FORWARD-LOOKING
• CRITICAL THINKING

Intellectual outputs

O1 - Teaching modules on emergent interdisciplinarity in advanced STEM topics (AI, QC, climate change, ….)

O2 - Teaching modules on curricular interdisciplinary topics

O3 - Guidelines to design and implement modules on curricular interdisciplinarity and STEM emerging interdisciplinarity in pre-service teacher education

O4 - Open Education Resources for Blended modules and MOOCs

O5 - Recommendations for policy makers to promote interdisciplinarity and innovate prospective teachers education for STEM challenges

GO1. A new generation of secondary school teachers

GO2. Interdisciplinary research groups in computers science, mathematics and physics education, able to support the process to align formal education (university and secondary school) with a fast-changing world.

GO3. New blended courses for interdisciplinary pre-service teacher education

GO4. New approaches, pedagogies and methods to foster interdisciplinarity

ExpRes1: a model of interdisciplinarity for preservice teacher education.

ExpRes2-5: to design and test innovative teaching materials and courses

ExpRes3-4: examples of STEM practices to develop“language skills, critical thinking and creativity” and “conceptualization, appropriation and meaningful learning in STEM education.

The challenging questions related to ..INTER-Disciplinarity between Mathematics and Physics (from a curricular point of view)

- What characterizes physics and mathematics *as disciplines*?
- Does school science give back the sense of physics and mathematics as disciplines?
- What is the relation between the «disciplinary identities» and the added value of their «integration»?

Disciplines and school science

School science often do not reflect both the nature of contemporary scientific endeavor and the history of science

Disciplinary authenticity should be pursued developing epistemic skills “by emphasizing the practices of doing science and generating scientific knowledge, while other, more historical-philosophical–oriented settings may emphasize critical reflection on the epistemological and historical processes of the development of scientific knowledge.”
(Kapon et al., 2018)

History-pedagogy-mathematics/physics (HPM/Ph): an innermost relationship (Tzanakis, 2016)

Intertwined and bi-directional co-evolution, interdisciplinarity as the essence of the historical evolution of the two disciplines.

Historical cases can mirror both disciplinary authenticity and interdisciplinarity

Maths → Physics

mathematics is the language of physics, not only as a **tool for expressing** ... but also as an indispensable, formative characteristic that shapes the physical concepts, by **deepening, sharpening, and extending their meaning**, or even endowing them with meaning.

Physics→ Maths

physics constitutes a natural framework for **testing, applying and elaborating mathematical theories,** methods and concepts, or even motivating, stimulating, **instigating and creating all kinds of mathematical innovations.**

Interdisciplinarity and disciplinary authenticity: a virtuous circle?

Interdisciplinarity ⟷ Disciplinary authenticity

1. an interdisciplinary approach could help in understanding better a discipline (ex. blackbody radiation, parabola and parabolic motion)

2. disciplinary knowledge could help in learning new disciplines or in dealing with new problems that are not yet organized in a discipline (ex. artificial intelligence)

ID ENTI TIES Enlightening Interdisciplinarity in STEM for Teaching

INTER-DISCIPLINARITY
vs.
A-DISCIPLINARITY, TRANS-DISCIPLINARITY or MULTI-DISCIPLINARITY

“Multidisciplinarity involves encyclopaedic, additive juxtaposition or, at most, some kind of coordination, but it lacks intercommunication and disciplines remain separate: it is, in fact, a pseudo-interdisciplinarity. True interdisciplinarity is integrating, interacting, linking, and focusing. […]. Transdisciplinarity is transcending, transgressing, and transforming, it is theoretical, critical, integrative, and restructuring but, as a consequence of that, it is also broader and more exogenous” (Thompson Klein, 2010

How can disciplines integrate, interact, be linked each other in perspective teacher education, in disciplinary-based institutional contexts?

DISCIPLINES AND AUTHENTIC RESEARCH PRACTICES

National Academies Committee on Facilitating Interdisciplinary Research (Kates, 2005): "Interdisciplinary research is a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialised knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or field of research practice"

Interdisciplinarity characterize authentic contemporary research practices BUT still needs disciplines!

INTER-Disciplinarity implies to start from «disciplines» and their «identities»

The term “discipline” contains the Latin root “discere”, whose meaning is to learn. Disciplines are re-organizations of the knowledge with the scope of teaching it.

Students, whilst building their knowledge, should also develop epistemic skills, like problem solving, modelling, representing, arguing, explaining, testing, sharing, evaluating the correctness of a reasoning/an argument.

From this perspective, disciplines can still play a relevant educational role, provided that they are explicitly pointed out as forms of knowledge organization historically developed and grounded on specific epistemologies

Levels of integration of disciplines

“**interdisciplinary thinking** is understood as the capacity to integrate knowledge and modes of thinking from two or more disciplines or established areas of expertise to produce a cognitive advancement in ways **that would have been impossible or unlikely through single disciplinary means**”

(Crujeiras & Jimenez-Aleixandre 2019).

Klein's second transition: Master students becoming teachers

At secondary school, knowledge is organized in disciplines, with some requests in the curriculum to address interdisciplinarity maths/physics

Students with a Bachelor in Mathematics or Physics or Computer science

Master students can attend Master degrees with a general background + Mathematics or Physics or Computer science education

Klein's second transition: Master students becoming teachers

Is it possible, collaborating, to provide prospective teachers with *suitable* knowledge to address interdisciplinarity in high school?

What goals of interdisciplinary teaching, what does disciplinary teaching gain and what obstacles can we meet?

The main issues: level of details, epistemological knowledge of their own and the other main discipline, … other issues?

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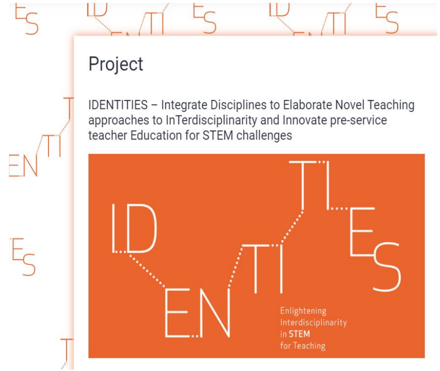
Goals of the IDENTITIES project

Integrate Disciplines to Elaborate Novel Teaching approaches to InTerdisciplinarity and Innovate pre-service teacher Education for STEM challenges

Design of innovative and **transferable teaching modules** to be used in the context of teacher education

- ➔ with special focus on the **links between Physics, Mathematics and Computer Science**.
- ➔ to provide participants with **professional skills** to work on the analysis, design and implementation of **interdisciplinarity at secondary school.**



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UNIVERSITÀ DI PARMA

Approach to design and research in the IDENTITIES project

Mixing and integrating different theoretical perspectives in mathematics, physics and computer science education.

1) **every discipline is valued** with its own epistemological and methodological identity, as well as every **research tradition in didactics of disciplines**
2) experts in didactics of each discipline are involved in a process of **co-design and co-teaching**

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COMMON THEORETICAL APPROACH

"IDENTITIES" innovations

THE ROLE OF DISCIPLINES

Interdisciplinarity cannot ignore the meaning of "disciplines". The respect of the epistemological IDENTITIES of the single disciplines is the basic principle for the modules' design.

TWO TYPES OF INTERDISCIPLINARY TOPICS

A) Interdisciplinary curricular topics : "border problems" to make disciplines more engaging, relevant and meaningful.

B) Advanced STEM topics: intrinsically interdisciplinary

TOOLS FOR ANALYSIS OF INTERDISCIPLINARITY

A) Interdisciplinary taxonomy by Thompson Klein (2017): i. Theoretical, ii. Methodological, ii. Instrumental and iv. Critical interdisciplinarity

B) Boundary objects & boundary crossing mechanisms (Akkerman & Bakker, 2011)

C) The constructs -to be further elaborated - of epistemological and linguistic activators

From “Interdisciplinary mathematics education” handbook (Ch. 3 - Roth & Williams)

Fig. 3.1 The spectrum of interdisciplinarity in problem solving, after Williams et al. (2016)

Mono-disciplinarity →
multi-disciplinarity →
inter-disciplinarity →
trans-disciplinarity →
meta-disciplinarity →

‘interdisciplinary’ mathematics involves various sorts of conjunction of mathematics with other knowledge:

- one or more **other disciplines** (e.g. when mathematics is used as a tool within a science)

- just **extra-mathematical, even ‘everyday’ knowledge** (as in mathematical modelling of traffic flows)

“Genuine ‘inter’ disciplinarity emerges, when **mathematics interacts with other disciplines to become something new and different** (e.g. when mathematics, statistics and sociology become a new, hybrid ‘quantitative reasoning’, or in mathematical-physics, and mathematical-biology).”

From “Interdisciplinary mathematics education” handbook (Ch. 3 - Roth & Williams)

‘meta-disciplinarity’ : awareness of the nature of the discipline or disciplines involved.

- when one becomes **aware of the root disciplines**—including mathematics—in their relation and difference within inquiry, e.g. when the nature of ‘using evidence’ in history and in science becomes contrasted.
- the **epistemic qualities of the disciplines** become clearer, **conscious theoretical control** of the disciplines becomes possible.

This kind of **meta-knowledge can emerge from reflection on the relationship of mathematics or other disciplines with other knowledge** at any point on the above spectrum [...]

it may be desirable to think of a beyond-disciplinarity which is not only ‘meta’ in the above sense, but which we will term **‘knowingly un-disciplined’, i.e. to some extent freed from the disciplines that bind problem-solving and inquiry to disciplinary norms and their limits** (Williams, 2016).

Design of a teacher education instructional proposal for interdisciplinarity

Main theoretical frameworks and tools

- As tools to be shared to analyse **disciplines and interdisciplinary relationships:**
  - **Taxonomy about interdisciplinarity** (Thomson Klein, 2010)
  - **Family Resemblance Approach**
  - **Boundary objects and boundary crossing mechanisms** (Akkerman & Bakker, 2011)

Thomson Klein taxonomy

Methodological Interdisciplinarity (MI): a method or a concept is taken from one discipline and applied in another to verify a hypothesis, formulate a theory or answer to a research question. The main goal is to improve the quality of results obtained in a single discipline. There is a contamination of epistemological knowledge, the borrowing of some theoretical tools from another discipline can give us a new structure of the original discipline.

Instrumental Interdisciplinarity (II): when MI serves some special needs of a single discipline. In the 80ies, instrumental interdisciplinarity gained visibility in informatics, biotechnology, or biomedicine (development of new discipline).

Theoretical Interdisciplinarity (TI): is an evolution of the MI and it involves a more holistic, general view and a more coherent epistemology. The main results are the elaboration of conceptual frameworks during the analysis of problems, the integration of propositions across disciplines and the new synthesis funded on the connection between models and analogies.

Critical Interdisciplinarity (CI): questions the dominant structure of knowledge and the educational system to transform it. It can destroy part of the system for reconstructing it. The deconstructing process and the seeking for disciplinary limits are the base for a new epistemology. Asking critical questions and looking for a common answer is part of the process of building new correspondences. The questions and the disciplines put in correspondence have changed, the solidity of their borders crumbles and a common basis can raise.

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FRA

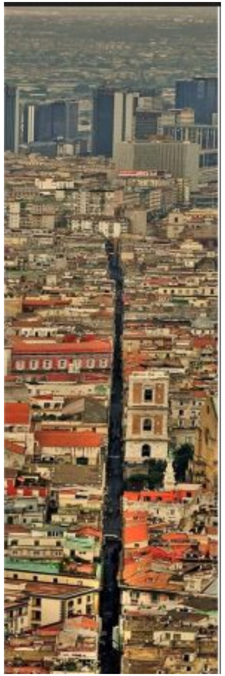
FRA “wheel” (Family Resemblance Approach; Erduran & Dagher, 2014)

Cognitive-epistemic stystem aspects	Aims and values	The scientific enterprise is underpinned by adherence to a set of values that guide scientific practices. These aims and values are often implicit and they may include **accuracy, objectivity, consistency, scepticism, rationality, simplicity, empirical adequacy, prediction, testability, novelty, fruitfulness, commitment to logic, viability, and explanatory power**.
	Scientific Practices	The scientific enterprise encompasses a wide range of cognitive, epistemic, and discursive practices. Scientific [epistemic] practices such as **observation, classification**, and **experimentation** utilize a variety of methods to gather observational, historical, or experimental data. Cognitive practices, such as **explaining, modelling, and predicting**, are closely linked to discursive practices involving **argumentation** and **reasoning**.
	Methods and methodological rules	Scientists engage in disciplined inquiry by utilizing a variety of **observational**, **investigative**, and **analytical methods** to generate reliable evidence and construct theories, laws, and models in a given science discipline, which are guided by particular methodological rules. Scientific methods are revisionary in nature, with different methods producing different forms of evidence, leading to clearer understandings and more coherent explanations of scientific phenomena.
	Scientific knowledge	**Theories, laws, and models** (TLM) are interrelated products of the scientific enterprise that generate and/or validate scientific knowledge and provide logical and consistent explanations to develop scientific understanding. Scientific knowledge is holistic and relational, and TLM are conceptualized as a coherent network, not as discrete and disconnected fragments of knowledge.

Table 1: FRA categories (from Erduran and Dagher 2014a) – adapted from Yeh *et al,* (2019, p295)

Social-Institutional system aspects	Professional activities	Scientists engage in a number of professional activities to enable them to communicate their research, including conference attendance and presentation, writing manuscripts for peer-reviewed journals, reviewing papers, developing grant proposals, and securing funding.
	Scientific ethos	Scientists are expected to abide by a set of norms both within their own work and during their interactions with colleagues and scientists from other institutions. These norms may include organized skepticism, universalism, communalism and disinterestedness, freedom and openness, intellectual honesty, respect for research subjects, and respect for the environment.
	Social certification and dissemination	By presenting their work at conferences and writing manuscripts for peer-reviewed journals, scientists' work is reviewed and critically evaluated by their peers. This form of social quality control aids in the validation of new scientific knowledge by the broader scientific community.
	Social values of science	The scientific enterprise embodies various social values including social utility, respecting the environment, freedom, decentralizing power, honesty, addressing human needs, and equality of intellectual authority.
	Social organizations and interactions	Science is socially organized in various institutions including universities and research centres. The nature of social interactions among members of a research team working on different projects is governed by an organizational hierarchy. In a wider organizational context, the institute of science has been linked to industry and the defence force.
	Political power structures	The scientific enterprise operates within a political environment that imposes its own values and interests. Science is not universal, and the outcomes of science are not always beneficial for individuals, groups, communities, or cultures.
	Financial systems	The scientific enterprise is mediated by economic factors. Scientists require funding in order to carry out their work, and state- and national-level governing bodies provide significant levels of funding to universities and research centers. As such, these organizations have an influence on the types of scientific research funded, and ultimately conducted.

The metaphor of boundary and liminality: boundary zones to inhabit or borders to overcome?



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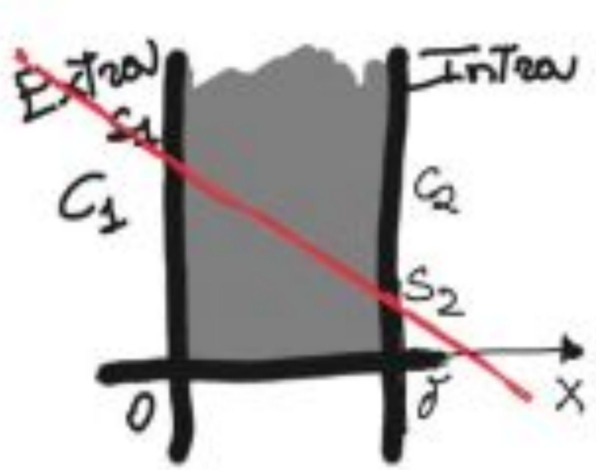

A possible framework and some steps forward

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

Thompson Klein J. (2010)
A taxonomy of interdisciplinarity.
The Oxford handbook of interdisciplinarity, 15, 15-30

Kapon, S., Erduran, S. (in press). Crossing boundaries – Examining and problematizing interdisciplinarity in science education. *Engaging with Contemporary Challenges through Science Education Research: Selected papers from the ESERA 2019 Conference*

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

Boundary people

Boundary objects

Boundary crossing (learning mechanisms)

- *Coordination*
- *Identification*
- *Reflection*
- *Transformation*

Akkerman & Bakker, 2011

Boundary Objects

Boundary Objects -
An ambiguous nature

Both – and: Objects that **enact the boundary** by addressing and articulating meanings and perspectives (multivoicedness) of various intersecting worlds.

Neither – nor: objects that **move beyond the boundary** in that they have an unspecified quality of their own.

This ambiguity creates a **need for dialogue**, in which meanings have to be negotiated and from which something new may emerge → if made explicit, the **ambiguous character can be turned into learning opportunities**

Identification

<u>Recognition and enhancement of differences</u>, through a dialogic process, in terms of:

- practices and methods
- values
- disciplinary knowledge

which have uncertain demarcation lines.

Coordination

<u>Communicative connection</u> that is established by tools that belong to the different "areas", like boundary objects necessary to find new translation / clarification criteria in order to find a new balance and share new meanings.

Reflection

In the interaction between the different "areas", <u>recognition of one's identity</u> in terms of:

- practices and methods,
- values,
- disciplinary knowledge.

opportunity to see through the eyes of other

Transformation

<u>Profound changes, in one or both disciplines</u>, in terms of:

- practices
- values
- knowledge

potentially allowing the *creation of a new border practice*

Akkerman-Bakker learning mechanisms to design ID activities

In crossing the disciplines' boundaries, it is not taken for granted that such learnings will take place ("learning potentials").

- Each learning mechanism has its own interdisciplinary processes that must be properly activated.

If we consider:

- an **interdisciplinary topic** as a boundary object between disciplines
- an **activity** on that topic as a boundary crossing

it could be essential to ask **which learning potentials** are enabled.

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