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IDENTITIES

Enlightening Interdisciplinarity in STEM for Teaching

Teaching modules on curricular interdisciplinary topics

- Intellectual Output O3 -

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Introduction to curricular interdisciplinary topics

In IDENTITIES two types of interdisciplinary topics have been addressed and are implemented in two types of modules (https://youtu.be/CSBwQixd-vI): STEM advanced interdisciplinary topics and curricular interdisciplinary topics concerning "border problems".

In this document, we present the four modules of the second type. More specifically they are examples of interdisciplinary epistemological curricular issues. Consistently to the approach of the project, the modules implement a definition of interdisciplinarity (Alvargonzález, 2011), which implies a crucial role by the disciplines and their identities (https://youtu.be/YEINsxehnxI). Interdisciplinarity, in fact, is used as a lever to uncover the epistemological cores of the disciplines by confronting them on a common boundary theme.

These modules are modulable so that a teacher can implement or combine also blocks of activities. The four modules follow a general structure: Introduction; becoming explorers, becoming students, becoming analysts, and aim to establish a boundary zone by introducing boundary objects, and activating a variety of boundary-crossing mechanisms (Akkerman & Bakker, 2011) (https://youtu.be/fK0XvtFeO_U).

These modules are intended to develop learning in the disciplines and their interactions for secondary teachers who should teach interdisciplinary topics either in disciplinary courses or in an interdisciplinary setting. They have been designed by interdisciplinary teams, in strict collaboration among the partners. Special attention is devoted to the linguistic dimension which furtherly characterizes the IDENTITIES approach to interdisciplinarity (https://youtu.be/vQV7Id3JIVA).

The first module is on Cryptography, which is an interdisciplinary domain in itself, at the interface between mathematics and informatics. This module has been developed as a curricular interdisciplinary module; it is however noticeable that Cryptography is also crucial for societal challenges. The last block of the module corresponds to an activity of design of further modules on cryptography.

The second module focuses on Linguistic and epistemological activators of interdisciplinarity. The aim of this module is to provide students with analytic tools to identify disciplinary and interdisciplinarity issues. This module deals with logical, linguistic, and epistemological issues, with a focus on possible ambiguities in scientific discourse.

The third module deals with Parabola and Parabolic motion, as an example of the intertwining between Mathematics and Physics. The module comprises historical episodes to make visible the structural role of mathematics for Physics and vice-versa, allowing genuine interdisciplinary experiences.

The fourth module focuses on Modelling in Mathematics and other disciplines. The module has been designed to emphasize the contribution of different disciplines to an authentic modelling process suitable for secondary school students, with a particular emphasis on the role of mathematical modelling in other disciplines or in real-life problems.

All the modules have been tested in at least two different contexts. The module on cryptography has been tested in both the IDENTITIES summer schools, as well as in preservice teacher courses in Montpellier, Bologna and Milan (in collaboration with UNIPR). The module on linguistic and epistemological activators of interdisciplinarity has been tested in the second summer school of IDENTITIES and in partial implementations in Montpellier, Parma and Bologna, in contexts of preservice teacher education. The module on Parabola and Parabolic motion has been implemented both in the first summer school of IDENTITIES (online) and six times in Bologna, Parma and Milan, both in contexts of preservice and in-service teacher education. The module on Modelling has been partially tested in Bologna and Montpellier and fully implemented in Milan in a strict collaboration between UNIPR, UNIBO, and UM.

The materials reported in this document and published in the project's website (https://identitiesproject.eu/modules/) are the last version, resulting from the processes of revision that followed the implementations.

All the materials for the IDENTITIES modules (presentations, worksheets, spreadsheets, questionnaires, …) are uploaded on the project website which is hosted by the servers of the coordinator institution, in compliance with all European regulations on data protection. Moreover, we stress that for each possible material, we uploaded an editable and a non-editable format. For the non-editable format, we uploaded a PDF. For the editable ones, we decided to adopt only the OpenDocument format (odt for text documents, odp for presentations, ods for spreadsheets) that can be used both in free and in proprietary softwares. Exceptions to these formats are, for example, videos (referenced as Youtube links), pictures (uploaded as JPEGs) or Netlogo simulations (uploaded as nlogo files compressed in zip folders) which do not have any OpenDocument equivalents.

In this document, the materials used in the implementations are linked within the overview of the modules. In the modules' description, three different groups of icons are used to orient reading. In the followings, we report a summary but for an extensive description of the icons inventory, we refer to Intellectual Outputs 4 and 5 (https://identitiesproject.eu/identities-final-intellectual-outputs/). The first group refers to the keywords related to the IDENTITIES framework on interdisciplinarity (see Figure 1).

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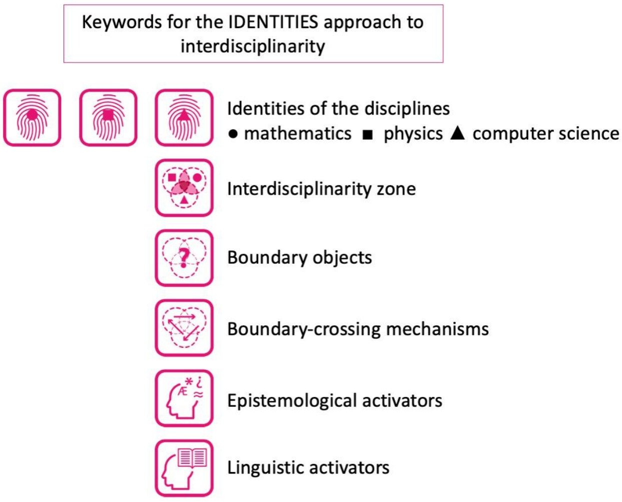

Fig. 1. The first group of icons

The second set of icons (see Figure 2) refers to the keywords related to the structure of the IDENTITIES modules, with respect to the role of participants.

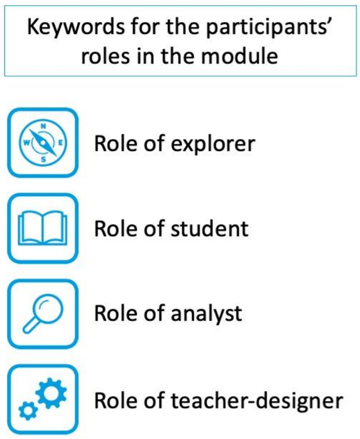

Fig. 2. The second group of icons

The third set refers to the keywords related to the type of participants' engagement in the activities of the IDENTITIES modules (see Figure 3).

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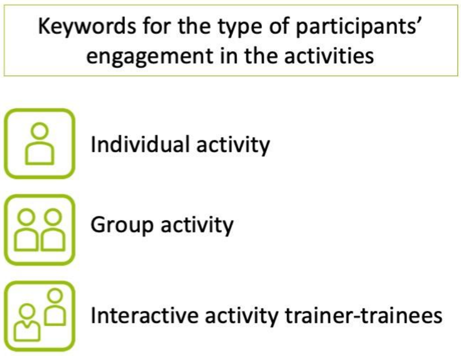

Fig. 3. The third group of icons

The Module on Cryptography

by Michael Lodi, Marco Sbaraglia, Simone Martini (UNIBO), Evmorfia-Iro Bartzia, Viviane Durand-Guerrier, Simon Modeste (UM)

Published online at: https://identitiesproject.eu/cryptography/

Introduction

We chose cryptography because, nowadays, it is an interdisciplinary domain in itself (Durand-Guerrier, Meyer, & Modeste, 2019). Both mathematical elements (e.g., proofs, number theory) and Informatics elements (e.g., computational complexity, systems design, programming) are fundamental to solving the relevant social, technological, and scientific challenges it poses. Moreover, some cryptography elements encompass intertwined aspects of Informatics and Mathematics (for example, one-way functions are both well-defined mathematical functions and programs that satisfy specific security and efficiency criteria).

The topic seems halfway through O2 and O3: while cryptography is crucial for today's societal challenges and its study involves different communities, the two most important disciplines involved (Informatics and Mathematics) are still very recognisable. While, historically, cryptography was in the realm of Mathematics, and while Informatics started as only a tool for faster computations, modern cryptography and its fields of application would not exist without Informatics. The current research in the field of cryptography stimulates a dialectic between the two disciplines, from Informatics to Mathematics (e.g., requiring new research in elliptic curves) and in reverse (e.g., using theorem provers to validate cryptographic properties). As said, cryptography still allows for "disciplinary projections": elements of the two disciplines are very recognisable inside the field (analogously to what happens in bicultural societies[1]). We choose didactic activities where these projections can shed light on important disciplinary concepts, like computational complexity for Informatics and linear systems for Mathematics. The projections can stimulate exploration and learning of some relevant topics and ideas of each discipline, not only in the specific scope of cryptography but also in other Informatics and Mathematics areas. Moreover, this can foster the exploration of general interactions between the two disciplines.

Consequently, developing learning in both disciplines and their interactions is relevant for secondary teachers who should teach cryptography either in Mathematics courses, Informatics courses, or interdisciplinary courses and projects.

We consider the need to introduce cryptography as a social issue of contemporary society (ENISA, 2016) (following a long-term presence in human history from ancient Greece to nowadays) because Cryptography is at the core of many of the economic, social, and political interactions that happen in our interconnected, globalised digital society. That is

[1] A good analogy can be bicultural identity or biculturalism, rather than multiculturalism (e.g. the coexistence of Europeans and Maori in New Zealand: the integration is clear, but is still very possible to recognize the two cultures).

why our module starts with a discussion on end-to-end encryption, the debate around its societal advantages and risks, and stimulating the need to understand how it works to form an informed opinion. Moreover, Informatics education research agrees on the fact that communicating in secret and trying to decrypt messages without knowing the key is engaging and motivating for students (Lindmeier & Mühling, 2020).

We choose the Didactical Engineering methodology relying on the Theory of Didactical Situations (Brousseau & Warfield, 2020), widely used for decades in Mathematics Education. Learning this methodology can be useful for student teachers as well.

We choose a public-key cryptography activity (based on a computationally hard problem on graphs) for epistemological and didactical reasons. Epistemologically, Informatics and Mathematics are deeply interconnected in the cryptography research field and discipline, and the activity, as we will see, can bring up many topics like algorithms, computational complexity, graphs, matrices, and linear systems. Educationally, informatics and cryptography have an inherent potential for *adidacticity*, that is, the potential for learning with a strong autonomy left to students' interactions with the problem. In fact, if one is trying to find the secret key of a cryptosystem (where encryption and decryption algorithms are public), the supposed key can be tested by decrypting the messages that have been encrypted with that key and see if the result is the original plaintext message. Analogously, in computer programming, students can autonomously test their program and check if it works by comparing the desired and actual result of the computation without waiting teacher's validation.

Becoming explorers

Aims: Making students aware of the fact that cryptography is crucial today by contextualising it in a social debate about end-to-end encryption and backdoors. Students should realise what disciplines are involved and what knowledge they need to understand and form an opinion in a debate. Moreover, by analysing a historical piece on the birth of modern cryptography, students see how Informatics and Mathematics are intertwined in cryptography, beginning with *disciplinary projections*. During all the activities, students start encountering basic terminology about cryptography.

Activities: Two individual activities. The first is watching an outreach video about how end-to-end encryption works (the fact that messages are fully encrypted from the sender to the receiver, so no one in the middle can read them) and the opportunity and risks of

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governments putting a backdoor (a way to decrypt those communications) for security reasons. The second one is reading an outreach text about the birth of asymmetric encryption, highlighting the interaction between mathematicians, computer scientists, and engineers who discovered it. After the two activities, students are given a reflection form about: skills needed to understand the debate; disciplines they recognise in the historical piece and their interactions; disciplinary-specific and crypto-specific terminology they found; initial thoughts about using the crypto interdisciplinary potential to teach crypto, Informatics and Mathematics in schools.

The participants introduce themselves and "break the ice" on interdisciplinarity and cryptography (pdf, editable format)

The participants watch two videos about end-to-end encryption (video 1, video 2)

The participants read a text about the birth of RSA (pdf, editable format)

The participants reflect on the activities they experienced, guided by some open-ended questions (pdf, editable format)

Becoming students

Aims: Students experience an example of a classroom activity designed according to the Theory of Didactical Situation (TDS). They will learn about public-key cryptography, explore the ideas of computational complexity and one-way functions, and manipulate

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interdisciplinary objects like functions, graphs, matrixes, and linear systems. From teachers' perspective, they will also experience firsthand how a didactical situation is organised.

Activities: We start with a brief presentation on the fundamental elements of asymmetric cryptosystems. Then, we present a cryptosystem based on the perfect dominating set problem on graphs (Bell et al., 2003) and show how it can be used to encrypt a message. After that, students are split into three groups: each group has to decrypt the same secret message but has different information on cryptographic and mathematical aspects of the system (i.e., in terms of the TDS, each group has a different organisation of the milieu) and an autonomous way to verify if they solved the problem (adidacticity). Afterwards, each group presents and discusses its strategies to decrypt the message. Finally, instructors lead an institutionalisation phase, based on the groups' presentations, to formalise the disciplinary aspects behind the activity. The different organisation of the three groups leads to different perspectives and approaches to the task and is intended to help student teachers think about the interdisciplinary objects encountered.

The participants participate in a presentation and interactive lecture on fundamental cryptography concepts (pdf, editable format)

The participants are introduced to how to encrypt a message using graphs (pdf, editable format)

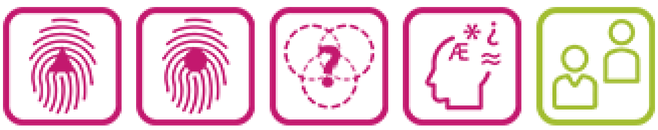
The participants in groups try to decrypt a secret message

Group A (pdf, editable format)

Group B (pdf, editable format)

Group C (pdf, editable format)

The participants present their results; instructors discuss the approaches and formalise some aspects of the activity (institutionalisation) (pdf, editable format)



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Becoming analysts

Aims: together with the interdisciplinary analysis explained in the short version, students are also given some TDS methodological tools to analyse the previous learning experience also from a learning design point of view.

Students are given “raw materials” to be analysed both with the same interdisciplinary tools and in light of the TDS in order to design a new didactical situation on a different topic, which also takes advantage of the interdisciplinarity between Mathematics and Informatics (within cryptography or outside of it)

Activities: First of all, students are given raw teaching materials (es. about the Fibonacci sequence and its computation, and about Primes factorisation and its relationship to computational complexity and cryptography) and asked to analyse it from disciplinary, interdisciplinary and didactical perspectives with guiding questions. After that, students are taught some principles of TDS. Finally, students are asked to design in groups a teaching activity (based on TDS) on one of the analysed topics by leveraging the disciplinary and interdisciplinary aspects they found.

The participants watch divulgation videos about interdisciplinary frameworks (videos)

The participants reflect on interdisciplinarity in activities they experienced, guided by some open-ended questions (pdf, editable format)

The participants explore individually "raw" teaching material that has the potential to be used to design interdisciplinary activities between CS and Math (inside and outside cryptography) (pdf, editable format)

The participants analyse in groups the teaching materials guided by some open questions (pdf, editable format)

The participants follow a lecture about the Theory of Didactical Situations (pdf, editable format)

Becoming designers

Aims: together with the interdisciplinary analysis explained in the section above, students are also given some TDS methodological tools to analyse the previous learning experience also from a learning design point of view.

Students are given "raw materials" to be analysed both with the same interdisciplinary tools and in light of the TDS in order to design a new didactical situation on a different topic, which also takes advantage of the interdisciplinarity between Mathematics and Informatics (within cryptography or outside of it)

Activities: First of all, students are given raw teaching materials (es. about the Fibonacci sequence and its computation, and about Primes factorisation and its relationship to computational complexity and cryptography) and asked to analyse it from disciplinary, interdisciplinary and didactical perspectives with guiding questions. After that, students are taught some principles of TDS. Finally, students are asked to design in groups a teaching activity (based on TDS) on one of the analysed topics by leveraging the disciplinary and interdisciplinary aspects they found.

The participants design an interdisciplinary learning activity (pdf, editable format)

The Module on Linguistic and epistemological activators of interdisciplinarity

by Viviane Durand-Guerrier (UM), Veronica Bagaglini (UNIBO), Laura Branchetti (UNIMI in collaboration with UNIPR), Lorenzo Pollani (UNIPR)

Published online at: https://identitiesproject.eu/linguistics-and-epistemology/

Introduction

The module has been designed as a general module to provide students with a more conscious approach to scientific texts, both as senders and receivers. It also intends to offer analytical tools that enable the recognition of disciplinary identities and curricular interdisciplinarity as they are presented in texts about scientific issues (historical texts, scientific papers, and textbooks). For this reason, the module deals with logic, linguistic, and epistemological issues with a particular focus on the impact of difficulties that an ambiguous or unclear scientific discourse can have on the comprehension of a message. The awareness of those aspects is important for understanding the texts adequately and deeply.

The IDENTITIES approach for the design and implementation of the module is mainly evident in the choice of the following design principles:

1. keeping logical, linguistic, and epistemological technicalities as simple as possible in order to focus attention on the potential that the logic, linguistic and epistemological perspectives can add to the analysis of the interdisciplinarity.
2. observing the scientific communication process, in its norms and needs, through the logic, linguistics, and epistemology approaches (Durand-Guerrier, 2008; Grice, 1975; Halliday & Martin, 1993; Habermas, 2003).
3. recognizing and strengthening disciplinary identities in the curricular interdisciplinary discourse through recognizing differences and similarities among various disciplinary communities in the communication of scientific topics.
4. reflecting on the boundary zone by introducing linguistic and epistemological activators (Bagaglini et al., 2021).
5. building a collaborative learning environment in which teachers and students from different disciplinary communities are willing to dialogue and share their disciplinary knowledge and perspectives in order to enrich their scientific identities.

Videos aimed to give the basics of the frameworks, terminology, and tools used in the module are available online.

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Becoming explorers

Aims: The first submodule focuses on exploring of processes involved in reading and understanding scientific texts, with particular attention to ambiguity and negation, also observed through translation issues.

Activities: Two activities are implemented. In the first activity, students are required to read a textbook excerpt and answer a questionnaire about comprehension, disciplinarity, and interdisciplinarity issues, with an empirical teaching perspective. In the second activity, the relevance of logical analysis is stressed in facing the ambiguities of negation statements; the students are asked to translate them into their own languages in order to avoid ambiguity, showing them the importance of syntactic choices in structuring sentences.

Pre-activity

The pre-activity concerns an analysis of the difficulties found by different STEM discipline students reading STEM textbooks. It is articulated in three tasks which students have to perform:

a) reading alone an excerpt from a STEM textbook (pdf);
b) answering the questionnaire proposed by teachers on the excerpt (pdf, editable format);
c) discussing in group the pre-activity, focusing on the excerpt's comprehensibility and its interdisciplinarity content.

Ambiguities, negation, interpretation, logical aspects

The activity aims to face the ambiguities by negation clauses of various statements in different disciplines. It is articulated in two tasks:

a) observing negation of quantified sentences addressing translation issues: logical issues (pdf, editable format);

b) discussing the relevance of the logical analysis for discussing ambiguities (pdf, editable format);

Becoming students

Aims: The second submodule aims to show the differences between scientific language and common language, stressing how language's use varies among disciplinary communities and the possible criticalities that non-experts can have in understanding the scientific message. Further, it aims to consider epistemological issues about rational shared norms in building scientific communication.

Activities: The second submodule includes two frontal lessons: one about linguistics and one about epistemology. The linguistic lecture is divided into two parts: the first part is dedicated to introducing the concept of scientific language, its historical development, its importance for the identity of the scientific community, and the specific characteristics which it assumes among disciplinary communities, in particular observing syntactical, morphological, lexical, and textual features; the second part is the explanation of what is implicit contents, how it structures the text and the negative consequences that they can have in activating misconceptions in students building their scientific knowledge. The epistemological lecture introduces Habermas' rationality construct in its three dimensions (epistemic, teleological, and communicative).

Linguistics and sciences: linguistic knowledge about scientific variety used

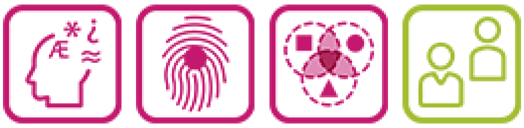
The linguistic activity provides the students with the linguistic knowledge and tools to detect STEM identities and interdisciplinarity narratives in textbooks.

The teacher explains the scientific variety's characteristics to the students on three levels: textual (with a focus also on the explicit and implicit contents), syntactical structures and lexicon; furthermore, the teacher also refers to scientific variety history, with a particular focus on Galileo Galilei's linguistic choices and genres used to communicate his discoveries (e.g. dialogue) (pdf, editable format);

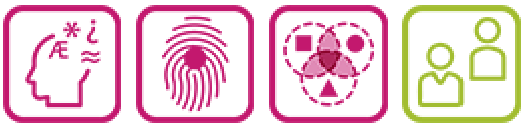
Habermas' rationality to analyze scientific reasoning and textbooks

The activity offers an epistemological analytical grid to the students in order to bring out disciplinary and interdisciplinary issues in students' reasoning and scientific textbooks' descriptions. The activity is articulated in two tasks:

a) conjecturing and proving statements about the following question: "what is it possible to say about the divisors of two consecutive natural numbers?" (pdf, editable format);



b) explaining the construct of Habermas' rationality to analyze students' conjectures and proofs.



Becoming analysts

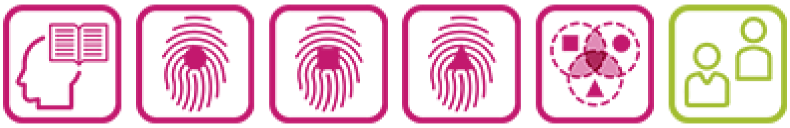
Aims: The third submodule aims to transform previous linguistic and epistemological knowledge into two analytical grids: the first looks at the scientific text's textual and syntactical structure, lexicon, and content; the second aims to bring out epistemological disciplinary issues. A second goal is to make the students aware of the complex organisation of the scientific discourse aimed to represent disciplinary images.

Activities: The grids are used by students to point out the potentialities and criticalities of scientific texts in conveying disciplinary identities and interdisciplinarity, especially considering a didactic point of view. The students are requested to read a textbook excerpt, analyze it, and, subsequently, reformulate it using everyday language and different genres, such as the Galilean dialogue, making the implicit information of the source text explicit.

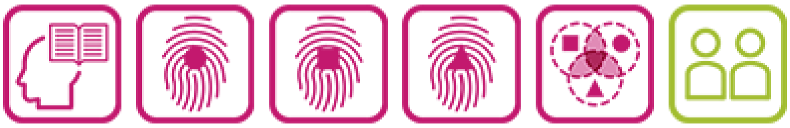
Linguistics, disciplinary and interdisciplinary knowledge: a linguistic grid

The activity consists of the explanation and usage of the linguistic grid. It is performed in three steps:

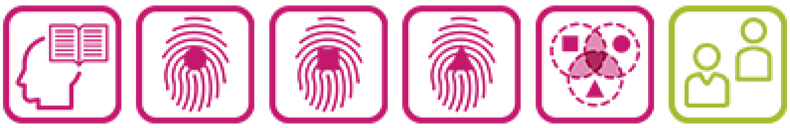
First, the teacher proposes scientific textbook excerpts and a linguistic grid to analyze them and explains how the grid guides the students in critically observing the excerpts proposed (and, in general, a text) and how it facilitates the recognition of disciplinary and interdisciplinary contents as they are presented in them (pdf, editable format);



After the explanation of the grid, the students analyze textbook excerpts in groups through the linguistic grid (pdf);



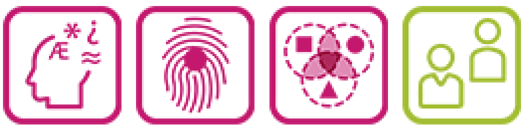
Finally, students and teacher discuss the analysis of the textbook excerpt together, sharing thoughts about the use of language in the excerpt and how it represents disciplinary and interdisciplinary contents.



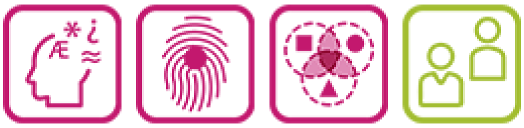
The epistemological grid to analyze scientific reasoning in scientific texts

The epistemological activity is divided into three parts.

At the beginning of the activity, the teacher explains the students' reasoning (pdf, editable format);



The students are required to discuss with the teacher their thoughts about the explanation;



After the first discussion, the students read and analyze two excerpts extracted from two scientific textbooks (pdf);

The teacher activates a second discussion about the textbooks.

Wrapping up

The last activity aims to sum up what has been explained and practised before in order to have a complex but critical approach to scientific texts. It gives the students the competence and the awareness of the complexity of disciplinary and interdisciplinary representations in texts. It includes two tasks:

a) analysis of a new textbook excerpt using the linguistic and epistemological grids;

b) asking the students for a reformulation of a textbook excerpt about the parabolic motion proof reproducing and renovating the textual structure of Galileian dialogue (pdf, editable format).

Post-activity

The final activity is a questionnaire for the students in order to check their comprehension of the module (pdf, editable format).

Download the module's lesson plan (pdf, editable format)

The Module on Parabola and parabolic motion

by Laura Branchetti (UNIMI in collaboration with UNIPR), Paola Fantini, Olivia Levrini, Sara Satanassi (UNIBO)

Published online at: https://identitiesproject.eu/parabola-and-parabolic-motion/

Introduction

The module concerns the curricular themes of parabola and parabolic motion. The themes have been chosen since, even if they are obviously interrelated, habits, textbooks, and school practices have progressively led to the establishment of school narratives that have short-circuited the deep interdisciplinary connections that characterized the historical development of the two disciplines. The historical episodes are reconstructed as two emblematic cases to highlight the structural role of mathematics in physics and vice versa. The module has been designed to emphasize the connections so as to both make the epistemological structures of the disciplines visible and create a space where the student-teachers were encouraged to make deep interdisciplinary experiences.

The IDENTITIES approach for the design and implementation of the module is mainly evident in the choice of the following design principles:

- Keep disciplinary technicalities as much simpler as possible so as to emphasize the interdisciplinary potential of the topic that emerges by analysing the theme from a historical, representational, and epistemological perspective (Renn et al., 2001)
- Unpack the epistemic core of disciplinary knowledge through the Family Resemblance Approach (Erduran & Dagher, 2014)
- Establish the boundary zone by introducing boundary objects ("curve-trajectories" and "proof"), and activating a variety of boundary-crossing mechanisms (Akkerman & Bakker, 2011)
- Create a safe learning environment, where student-teachers feel free to play with their ideas and are supported to find an equilibrium and inhabit the tension between feeling at their disciplinary home and accepting the risk of thinking out of the box and embracing the ambiguity of interdisciplinarity.

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Becoming explorers

Aims: The first submodule aims to introduce the tools to analyse the disciplines' identities and their integration. To this scope, the Family Resemblance Approach and the metaphor of the "boundary" are introduced. A further aim is to share their ideas on the knowledge that representations of curves embed and the criteria that can be used to establish if they are parabolas.

Activities: Three teamwork activities are implemented. The first one guides the students to get acquainted with the vocabulary of Akkerman and Bakker by sharing personal experiences of crossing boundaries and eventual difficulties they have met. The second one invites the students to reflect on aims & values of their disciplines, practices, methods, and forms of knowledge by sharing and commenting on examples of such epistemological elements. In the third activity, the student-teachers are invited, in group, to analyse a set of images that represents curves and point out criteria that can be used to establish if and why a curve can be recognised as a parabola.

Introduction to the module

Ice-breaking and boundary activities (pdf, editable format)

Introduction to the IDENTITIES project: disciplines, interdisciplinarity, and key questions (pdf, editable format)

Curricular and S-T-E-M advanced interdisciplinarity (video)

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Images of interdisciplinarity (pdf, editable format)

Taxonomy of interdisciplinarity (video)

Curves and trajectories

Parabola images and discussion (pdf, editable format)

Production of a home report about the group's discussion

Lenses to look at interdisciplinarity

Introduction to the boundary metaphor (pdf, editable format)

Introduction to boundary objects and boundary-crossing mechanisms (video)

Brainstorming on "What do you mean by science?"

Co-funded by the Erasmus+ Programme of the European Union
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Introduction to the Family Resemblance Approach (FRA) to reflect on disciplinary identities and their comparison (pdf, editable format)

NOS and FRA wheel survey (pdf, editable format)

Becoming students

Aims: The second submodule aims to unpack the interdisciplinary potential of the topic of parabola and parabolic motion, by analysing the theme from a historical, representational, and epistemological perspective. The analysis is carried out to show the co-evolution of the two disciplines and, specifically, to unveil boundary objects and boundary-crossing mechanisms that had a foundational role in the establishment or re-definition of the identities of physics and mathematics as disciplines.

Activities: Through interactive lectures, the student-teachers, in the role of "students", are guided to experience two parallel narratives: the "physics" narrative where the structural role of mathematics is emphasised in the discovery of parabolic shape of projectile motion and the establishment of physics as discipline; the "mathematics" narrative, where the structural role of physics was stressed in the historical evolution that led to the re-classification of conics in mathematics. In the middle, the student-teachers are involved in an activity focused on reflecting on the construct of proof in mathematics and in physics.

Conics and motions in the history of Mathematics and Physics

Parabolic motion and the birth of Physics as a discipline: Aristotle, Tartaglia, Guidobaldo, Galileo (pdf, editable format)

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

Epistemological differences between parabola images (pdf, editable format)

Parabola as a conic section. A historical dialogue between mathematics and physics: Euclid, Apollonio, Archimede, Witelo, Kepler (pdf, editable format)

Becoming analysts

Aims: The third submodule has two main related aims: 1) giving the participants the fundamental linguistic notion of the scientific language, the linguistic and the epistemological tools allowing them to analyse scientific texts; 2) recognising the elements of disciplinary's identities, boundary objects and boundary crossing mechanisms as they are represented in scientific texts (both historical texts and textbooks).

Activities: To the participants, epistemological and linguistic grids are provided as a summary or enrichment of the second submodule. Through this activity, they are guided to apply the disciplinary and interdisciplinary knowledge and tools they have learned as lenses to break down stereotypes and unpack how textbooks convey specific images of mathematics and physics and of their possible relationships.

Argumentation and proof at the boundary between Mathematics and Physics

Make a proof of Pythagora's theorem (pdf, editable format)

Proof in mathematics and the Galileo's proof analysis (pdf, editable format)

Co-funded by the Erasmus+ Programme of the European Union
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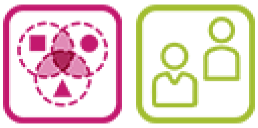
Text analysis

Linguistic tool for Physics textbook analysis (pdf, editable format)

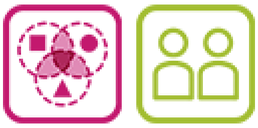
Textbook linguistic analysis: ad hoc questions grid (pdf, editable format)

Linguistic analysis of textbooks (Physics, volume 1, by James S. Walker, 2017) (pdf, editable format)

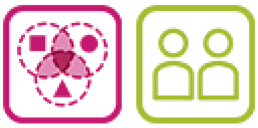
Habermas' rationality introduced as scaffolding to analyse a text (pdf, editable format)



Walker's Habermas analysis: guiding questions (pdf, editable format)



Epistemological analysis of textbooks (Physics, volume 1, by James S. Walker, 2017) (pdf, editable format)



Wrap-up activities

Discussion on the comparison between Galileo and Walker

Discussion on novel elements of activators (e.g. curves and proofs)

Production of a final report (pdf, editable format)

Download the module's lesson plan (pdf, editable format)

Co-funded by the Erasmus+ Programme of the European Union
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The Module on Modelling in mathematics and other disciplines

by Laura Branchetti (UNIMI in collaboration with UNIPR), Viviane Durand-Guerrier (UM), Giulia Tasquier (UNIBO), Berta Barquero, Carolina Pipitone (UB)

Published online at: https://identitiesproject.eu/modeling/

Introduction

The module concerns the curricular theme of modelling, which is transversal to mathematics, physics and other sciences, with specificities in the different disciplines but also deeply interdisciplinary in the case of mathematical modelling in other disciplines and in real-life problems. The themes have been chosen since modelling appears in secondary school curricula in all countries, but its interpretation can be affected by habits of the disciplinary community that can vary a lot among different disciplines. In particular, it can be flattened or trivialized when dealing with mathematical modelling in physics, or it can be turned into an object ("the model") rather than considering the process of modelling. The module has been designed to emphasize the contribution of different disciplines to an authentic modelling process suitable for secondary school students and exploiting only disciplinary contents and methods that can be considered curricular in all countries.

The contamination between different methods and issues is alternated to the disciplinary analysis of the questions posed of their relevance to the discipline, in order to make the epistemological role of models and modelling within different disciplines visible and create a space where the student-teachers were encouraged to make deep interdisciplinary experiences.

The IDENTITIES approach for the design and implementation of the module is mainly evident in the choice of the following design principles:

- Keep disciplinary technicalities as much simpler as possible so as to emphasize the interdisciplinary potential of the topic that emerges by modelling real problems and disciplinary problems and focus on the issues emerging in the process of modelling
- Unpack the epistemic core of disciplinary knowledge through the Family Resemblance Approach (Erduran & Dagher, 2014)
- Establish the boundary zone by introducing boundary objects ("model" and "approximation"), and activating a variety of boundary-crossing mechanisms (Akkerman & Bakker, 2011)
- Create a safe learning environment, where student-teachers feel free to play with their ideas and are supported to recognize the influence of disciplines in the formulation of questions to investigate a phenomenon. In particular, they will move from a paradigm of "modelling the real world", typical of some approaches to mathematical

modelling in education, to the paradigm of modelling as the elaboration of data collected and organized according to goals. Such goals could be related to issues posed by different agents (companies, societal agencies, research institutes, ..) or to the curiosity of the students themselves while exploring a situation.

Becoming explorers

Aims: The first submodule aims to involve students in a mathematical modelling experience and to make them deal with two directions of mathematical modelling: vertical and horizontal modelization (Yvain-Prebiski and Modeste, 2019). The situations concern life sciences and industrial sciences. We use the results of this contemporary epistemological study to analyze and support the relevance of some problems designed to foster the devolution of the mathematical modelling process to the students. Moreover, in this submodule, students are asked to reflect on the novelties, choices and difficulties that emerged when dealing with a problem formulated by members of other fields.

Activities: First, an a-didactical situation is proposed to students concerning life science and industry; they are involved into a milieu where their exploration, guided by a question and supported by suitable media, should make emerge modelling strategies that the trainer could institutionalize as vertical and horizontal modelization in the "Becoming students" phase. We will use the strategy of "realistic fiction" in order to reduce the complexity of horizontal mathematization. The second activity guides the students to get acquainted with the vocabulary of Akkerman and Bakker by making explicit the assumptions that make this approach to modelling a mathematical one (identification) and what new aspects of mathematics they met in this process. Moreover, they are asked to reflect on eventual difficulties they have met during the activity due to the fact that the problem was formulated within other fields.

Ice-breaking and boundary activities (pdf, editable format)

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

Introduction to the IDENTITIES project: disciplines, interdisciplinarity, and key questions (pdf, editable format)

Curricular and S-T-E-M advanced interdisciplinarity (video)

Images of interdisciplinarity (pdf, editable format)

Taxonomy of interdisciplinarity (video)

Modelling the growth of trees

Preliminary ideas about modelling in mathematics and physics (pdf, editable format)

A-didactical situation about the growth of trees (pdf, editable format)

Co-funded by the Erasmus+ Programme of the European Union
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Becoming students

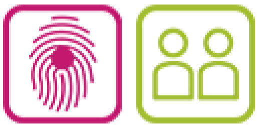
Aims: The second submodule aims to introduce the main epistemological features of mathematical modelling and modelling in sciences. After making explicit the notions of vertical and horizontal mathematization and their intertwining, students are introduced to the epistemological role of 'models and the game of modelling' in science and particularly when dealing with the issue of radiation and absorbance in the greenhouse effect. The purpose of the submodule is to discuss with the students the epistemological dimension of modelling in different disciplines, and to show that modelling is a boundary object that can trigger interesting identification and reflection learning processes at the boundary between mathematics and sciences at secondary school.

Activities: At the beginning, through interactive lectures, the student-teachers, in the role of "students", are guided to recognize what are the invariant practices of horizontal mathematization they carried out in the explorer phase, and how they interplay with context-specific practices. In the second activity, the student-teachers are presented with a lecture about epistemological issues that can represent a demanding challenge for students, and more generally for citizens, related to climate science. While usually the attention is posed to the difficulties due to the use of non-linear models whose features are very different from the classic and mechanistic view of modelling (Pasini, 2005), puzzling epistemological issues also arise when very basic models are used in a curricular introduction to the greenhouse effect, which could easily leave students skeptical and detached (Tasquier, Pongiglione & Levrini, 2014; Tasquier, 2015; Tasquier, Levrini & Dillon, 2016). After being presented with two different disciplinary epistemological aspects of modelling, students are asked to deal with mathematization in the organization of empirical data concerning the greenhouse effect into a mathematical model and come back to the scientific issues.

Simulation of a teaching situation and solution of the re-launched realistic fiction (pdf, editable format)

Vertical and horizontal mathematization and their relationships (pdf

Reflection about implementations in secondary school (pdf)



Production of a home report

Modelling in science: the case of the greenhouse effect

Modelling in science: questionnaires about the Cartographer and Palomar and about their own conceptions about modelling in science (pdf, editable format)

The interaction between matter and radiation: heat and temperature (pdf, editable format)

Experiments and empirical data about the interaction between matter and radiation (pdf, editable format)

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

Becoming analysts

Aims: The third submodule concerns the analysis of the mathematization in scientific modelling and interdisciplinary issues arising when different epistemologies of modelling are combined.

Activities: To the participants, epistemological and linguistic grids are provided as a summary or enrichment of the second submodule. Through this activity, they are guided to apply the disciplinary and interdisciplinary knowledge and tools they have learned as lenses to break down stereotypes about modelling procedures in sciences and mathematics, highlighting their similarities, differences and interplays.

Modelling and interpretation of empirical data related to the interaction between matter and radiation (pdf, editable format)

Modelling in science education: data from students' answers (pdf)

Boundary objects and boundary crossing

Introducing boundary objects and boundary-crossing mechanisms (video)

Discussing experiences as boundary people

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

Identification of mathematical and physical processes of modelling

Interdisciplinary analysis of modelling processes between mathematics and physics: the case of the interaction between matter and radiation

Analysis of coordination in interdisciplinary modelling: boundary crossing mechanisms in the activity about modelling of the interaction matter-radiation and horizontal mathematization in the activity about modelling of the interaction matter-radiation (pdf, editable format)

Wrap-up

Participants' presentations

The contribution of modelling to the development of interdisciplinarity at school: final discussion

Final report

Download the module's lesson plan (pdf, editable format)

Concluding remarks

The modules here presented are the results of at least two rounds of selection, design, implementation, revision. Each of them has been tested, fully or partially, in at least 2 different contexts.

The relevance of the innovative aspects of the modules concern: a) the place and role of epistemological issues in STEM education as a mean for understanding the relationships and the common backgrounds, if any, among physics, mathematics and informatics; b) the interrelation of STEM disciplines and history of sciences as a mean to foster interdisciplinarity; c) the methodology of didactical engineering for developing sound interdisciplinary teaching and learning activities consistent with epistemological analyses; d) the use of logic as an educational tool in a non-normative way aiming to foster prospective and in-service teachers' abilities to anticipate students' linguistic difficulties and cognitive diversity.

This output is targeted to teacher educators in contexts of pre-service or in-service teacher education. Because of the research approach and methods that have been used, the process of modules' development has produced research results, targeted to research communities in mathematics, physics, informatics, STEM education or to communities of the learning sciences.

The production of the module on cryptography has been methodologically framed within the methodology of Didactical Engineering (DE) (Artigue, 1994). This framework involves an iterative process of designing, testing, and revising the modules, according to back and forth dynamics between theoretical hypotheses and empirical results. The production of the other modules has been methodologically framed within the Design-Based Research (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003). Both the frameworks involve an iterative process of designing, testing, and revising the modules, according to back and forth dynamics between theoretical hypotheses and empirical results. They both have an explicit theoretical orientation that enriches the goal to design and realize good practices with the purpose of explaining why a teaching practice is more or less successful.

The results of the analyses have been presented in international conferences and are the object of (submitted or in progress) research papers.

The list of works (papers, theses, reports) and conference presentations is the following:

- Barelli, E., Barquero, B., Romero, O., Aguada, M.R., Giménez, J., Pipitone, C., Sala-Sebastià, G., Nipyrakis, A., Kokolaki, A., Metaxas, I., Michailidi, E., Stavrou, D., Bartzia, I., Lodi, M., Sbaraglia, M., Modeste, S., Martini, S., Durand-Guerrier, V., Bagaglini, V., Satanassi, S., Fantini, P., Kapon, S., Branchetti, L., & Levrini, O. (2022). Disciplinary identities in interdisciplinary topics: challenges and opportunities for teacher education. In G.S. Carvalho, A.S. Afonso & Z. Anastácio (Eds.), Fostering scientific citizenship in an uncertain world (Proceedings of ESERA 2021), Part 13 (co-ed. M. Evagorou & M.R. Jimenez Liso), (pp. 934-943). Braga: CIEC, University of Minho. ISBN 978-972-8952-82-2.
- Barquero, B., Barelli, E., Romero, O., Aguada Berta, M.R., Jiménez, J., Pipitone, C., Sebastià, G.S. (2021). Teacher education for interdisciplinarity: design of a module

about modelling coronavirus evolution. Presented at ESERA conference - 2021, 30 August - 3 September 2021 (online).

- Barquero, B. (2021). Questioning interdisciplinarity from society to school: Design and analysis of interdisciplinarity teaching projects. *Invited plenary lecture at Edu-SIMAI 2020+2021* (August 2021, online).
- Bartzia, E., Modeste, S., Lodi, M., Sbaraglia, M., Durand-Guerrier, V. (2022). Conception et organisation d'une situation didactique en cryptographie [Design and implementation of a Didactical Situation in cryptography]. Presented at the Didapro 9 DidaSTIC – 2022, May 18th-20th (Le Mans, France) (Poster paper, in French).
- Bartzia, E., Lodi, M., Sbaraglia, M., Modeste, S., Durand-Guerrier, V., Martini, S. (in submission). A Didactical Situation on Cryptography between Informatics and Mathematics.
- Branchetti, L. (2020). Interdisciplinarità tra fisica, matematica e informatica nella formazione iniziale degli insegnanti: il progetto IDENTITIES. [Interdisciplinarity between physics, mathematics and computer science in pre-service teacher education: the IDENTITIES project]. Presented at the SIF conference – 2020, September 14th-18th (online).
- Branchetti, L., Levrini, O. (2021). Disciplines and interdisciplinarity in STEM education to foster scientific authenticity and develop epistemic skills. Invited symposium presented at NARST – 2021, April (online).
- Casarotto, R. (2022). The "FRA wheel" as a teaching tool to elaborate on the identity aspects of physics and mathematics as disciplines in interdisciplinary contexts. Master thesis in Physics, Alma Mater Studiorum – University of Bologna. Advisor: Prof. O. Levrini. Co-advisor: S. Satanassi.
- Durand-guerrier, V., Bartzia, I., Branchetti, L., Lodi, M., Martini, S., Modeste, S., Sbaraglia, M. (2021). Teaching cryptography to foster interdisciplinarity between mathematics and computer science. Presented at ESERA conference - 2021, 30 august - 3 september 2021 (online).
- Gombi, A., "The foundational case of the parabolic motion: design of an interdisciplinary activity for the IDENTITIES project", master's thesis in physics, Alma Mater Studiorum—University of Bologna, advisor: Olivia Levrini, co-advisor: Sara Satanassi.
- Levrini, O., Branchetti, L., Cattabriga, A., Moruzzi, S., Viale, M. (2020). Interdisciplinarità tra matematica, fisica, linguistica ed epistemologia: linee guida e risultati di un'esperienza di formazione in servizio nel PLS-POT di Bologna [Interdisciplinarity among mathematics, physics, linguistics and epistemology: guidelines and results of an experience of in-service training within the PLS-POT project in Bologna]. Presented at the GEO-CRUI conference – 2020, June 15th-17th (online).
- Nipyrakis, A., Kokolaki, A., Metaxas, I., Michailidi, E., Stavrou, D. (2021). S-T-E-M student teachers analysing interdisciplinarity in the field of nanotechnology. Presented at esera conference - 2021, 30 august - 3 september 2021 (online).
- Pollani, L., & Branchetti, L. (2022). An experience of exploring the boundary between mathematics and physics with preservice teachers. *Pre-Proceedings of the Fourth*

Conference of the International Network for Didactic Research in University Mathematics, 330–339.
- Polverini, G. (2022). Exploring interdisciplinarity between physics and mathematics: the design of a linguistic and an epistemological tool for analysing texts about the parabolic motion, master's thesis in physics, Alma Mater Studiorum—University of Bologna, advisor: Olivia Levrini, co-advisor: Veronica Bagaglini and Sara Satanassi.
- Satanassi, S., Casarotto, R., Caramaschi, M., Barelli, E., Branchetti, L., & Levrini, O. (submitted). Exploring the boundaries in an interdisciplinary context through the Family Resemblance Approach: the dialogue between physics and mathematics.
- Satanassi, S., Branchetti, L., Fantini,. P, Levrini, O. (2021) Parabola and parabolic motion: crossing boundaries between physics and mathematics. Presented at ESERA conference - 2021, 30 August - 3 September 2021 (online).

The main results are:

a) the effectiveness of the boundary metaphor to name the boundary learning mechanism and to manage the tension between exploiting disciplinary identities and transgressing their boundaries (Casarotto, 2022);
b) the effectiveness of IDENTITIES interdisciplinary approach to regenerate curricular knowledge and develop epistemic and interdisciplinary skills needed to navigate the complexity of our society (Satanassi et al., submitted);
c) the recognition of epistemological and linguistic activators tools' value and effectiveness to unveil the epistemological core of the disciplines and their interdisciplinarity, to compare and integrate disciplinary knowledge;
d) the efficacy of epistemological activators and IDENTITIES approach to reflect and fill with meaning the intertwining between physics and mathematics overcoming the canonical instrumental function recognized usually associated with their reletionship;
e) the effectiveness of a didactical situation about cryptography in making students mobilise concepts, methods and practices of mathematics and informatics, moving between semiotic representations of the interdisciplinary objects involved (Bartzia et al., in submission).

Because of the richness of the data collected, further analyses are on going and the results will be presented in next conferences and published in research papers.

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