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IDENTITIES

Enlightening
Interdisciplinarity
in STEM
for Teaching

Teaching modules on emergent interdisciplinarity in advanced STEM topics

- Intellectual Output O2 -

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Introduction to STEM advanced 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 first type, whose themes are: COVID-19, Nanoscience and Nanotechnology, Simulations of complex systems, Climate change.
In spite of their evident differences, all the modules have common features that incorporate the key principles of the IDENTITIES project.

"Authentic" interdisciplinarity

The first common feature of all the modules is their "authentic" interdisciplinarity in two senses.
First of all, the modules are based on concepts that are intrinsically interdisciplinary and cannot be brought back to any of the traditional disciplinary contexts, or even to a sum of other S+T+E+M concepts.
Secondly, the modules refer to complex themes emerging from socio-scientific problems. Unlike the curricular ones, the themes are not yet necessarily part of teacher education and, more in general, are not yet "disciplinarized": they are not consolidated in stable disciplinary narratives within school and teacher education curricula. Didactic narratives are being invented and the role of disciplines is at issue.
In the modules, authentic Interdisciplinarity is operationally explored through the theoretical perspective of Akkerman and Bakker (2011) of the "boundary objects and boundary learning mechanisms" (https://youtu.be/fK0XvtFeO_U).

Disciplines matter

Coherently with the IDENTITIES approach to interdisciplinarity (https://youtu.be/YElNsxehnxI), in the modules, disciplines are valued for epistemological, institutional and identity reasons.
From an epistemological point of view, disciplines are stressed to play the role of grounding new explorations on a solid basis and protecting from the insecurity given by the uncertainty and ambiguity of a new experience.
From an institutional point of view, a special role is attached to mathematics, computer science and physics (the core disciplines chosen in IDENTITIES). The choice is aimed to facilitate the collocation of the modules in the principal institutional contexts considered in IDENTITIES, which are the university courses for pre-service teacher education within Physics, Mathematics and Computer Science master courses. In these contexts, students have different backgrounds and the exploitation of such disciplines has the role to make them feel "familiarity" with fundamental aspects of the themes. They are guided to recognise

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words/terms/expressions that can activate their background resources to grasp the novelty of knowledge integration and to reason on the role of their discipline in the new methods, argumentations, conceptualization and validation processes.

Epistemological and linguistic activators and the perspective of complexity

In order to manage the tensions that can emerge in navigating interdisciplinary boundary zone in search of both exploiting the disciplinary identities and transgressing them, the modules include and value "epistemological and linguistic activators".
Epistemological activators refer to special boundary or disciplinary objects that can support the activation of boundary learning mechanisms, that is, reflective comparisons within, between, and across disciplines (Ravaioli, 2020). Additional support for managing the tension can be provided by linguistic activators i.e., concepts, categories, or forms of linguistic representations that are used differently in different disciplines. The explicit comparisons of the entailed meanings ascribed in each discipline, help students unpack additional layers of the interaction between disciplines (https://youtu.be/vQV7Id3JIVA).
Since all these modules concern a complex STEM theme, a privileged source of epistemological and linguistic activators is represented by the perspective of complexity.
The perspective of complexity is, more or less explicitly, chosen to structure the boundary zone. The basic assumption is that, if complexity is properly addressed at school, it can be a source of knowledge, skills and attitudes, from which a student can be guided to develop systemic thinking, skills of embracing ambiguity and uncertainty, capacities to manage the tension between the need to feel at home and explore the unknown. Examples of keywords related to complexity, introduced and discussed in the modules, are: order-disorder-organization (systemic thinking), determinism-probability, linear causality, feedback-loop, intrinsic-emergent properties (embracing ambiguity and uncertainty), non-linearity, predictability-scenarios (future literacy).

The didactic approach

The contents of three modules are the result of the research process that, methodologically, coheres to the Model of Education Reconstruction (Duit et al., 1997), well known in Science education, whilst one module entirely coheres to the framework of Anthropological Theory of the Didactic (ATD), well known in the Didactics of Mathematics.
In spite of this distinction in the initial approach, the final structure of all the modules has been built according to ATD. Within the ATD, the step toward a change of paradigm in teacher education in the so-called "paradigm of questioning the world" (Chevallard, 2015) is approached using the "study and research paths for teacher education" (SRP-TE) (Barquero et al., 2018). The SRP-TE is an inquiry-based process combining practical and theoretical questioning of outside- and inside-school scientific activities. The approach is mainly

characterised by: i) the formulation of questions that are rich and relevant enough to be placed at the heart of pre-service teacher education programmes (becoming explorers); ii) the facilitation, through the questions, of epistemological and didactic analysis tools of disciplinary and interdisciplinary knowledge at stake (becoming students); iii) the detection of boundary objects and boundary-crossing mechanisms to switch on links between the disciplines and foster the analysis of interdisciplinary knowledge (becoming analysts). In the case of the present module, the SRP-TE is structured in four submodules. Each of them asks participants to assume different roles with regard to their interdisciplinary inquiry.

All the modules have been tested in several contexts. The module on Covid-19 has been tested in both the IDENTITIES summer schools, as well as in preservice teacher courses in Barcelona and Bologna. The module on Nanoscience and Nanotechnology has been tested in the first summer school of IDENTITIES and in further implementations in Crete and Barcelona in contexts of both preservice and inservice teacher education. The module on Simulations of complex systems has been implemented both in Bologna and in Barcelona in master courses for preservice teacher education. The module on Climate change has been partially tested in Bologna and in Crete, as well as fully implemented in the second summer school of IDENTITIES.

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. Each module is a set of activities whose implementation can last from 10 to 20 hours. However, its articulation is modular snd teacher educators can also implement blocks of activities of 3-5 hours.

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 software. Exception 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).

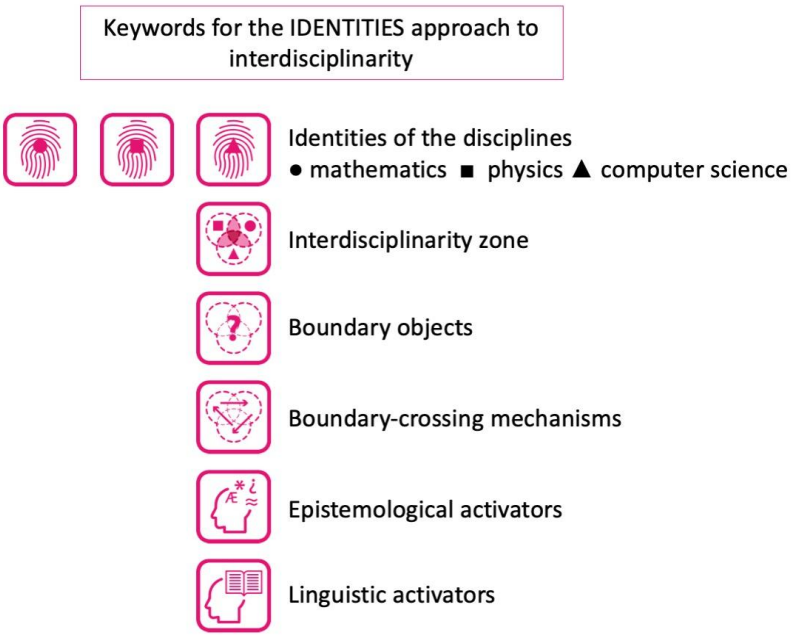

Fig. 1. The first group of icons.

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.

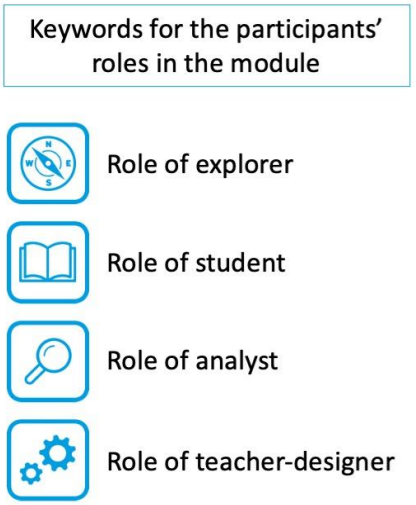

Fig. 2. The second group of icons.

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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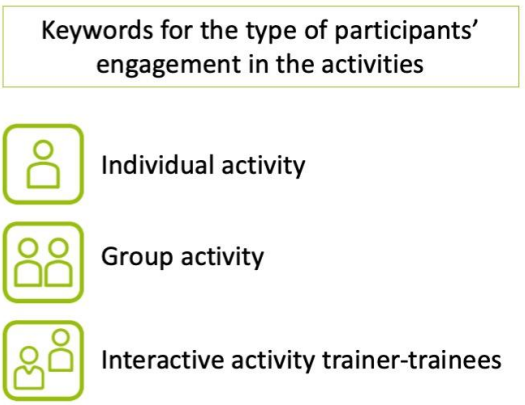

Fig. 3. The third group of icons.

The Module on COVID-19

by B. Barquero, C. Pipitone, O. Romero, M. R. Aguada Bertea, G. Sala-Sebastià, J. Gimènez (UB), E. Barelli (UNIBO)

Published online at:
https://identitiesproject.eu/models-modelling-and-simulation-to-highlight-the-interdisciplinarity-of-covid-19/

Introduction

The topic of modelling the evolution of COVID-19 was chosen in part due to its intrusion into our daily lives at the beginning of 2020. An authentic example of STEM advanced interdisciplinarity is recognised as one major issue for the society that required the collective effort of putting different disciplines to react in front of unexpected questions. Indeed, the COVID-19 pandemic has shown more than ever that students and, more in general, citizens need to understand how mathematics and scientific advances contribute to the understanding of societal phenomena. In addition, "the pandemic illustrates perfectly how the operation of science changes when questions of urgency, stakes, values, and uncertainty collide" (Saltelli et al., 2020). Specifically, it has emerged the need to explore what kind of knowledge can models and modelling provide, how we may interpret their predictions, and more in general, what contribution they provide to the understanding of such a complex issue.

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

- the formulation of questions that are rich and relevant enough to be placed at the heart of pre-service teacher education programmes (such as the initial questions about "how have STEM disciplines contributed to the societal understanding of the evolution of COVID-19? How can this interdisciplinary practice be transposed to secondary schools?")
- the facilitation, through the questions, of epistemological and didactic analysis tools of disciplinary and interdisciplinary knowledge at stake
- the detection of boundary objects and boundary-crossing mechanisms to switch on links between the disciplines and foster the analysis of interdisciplinary knowledge.

Becoming explorers

Aims: This first submodule concerns a first exploration of the topic-specific questions for interdisciplinarity, identification of the disciplines involved, detection of new terminology diffused to society, etc. The submodule finishes with the delimitation of possible lines of inquiry involving models and modelling as well as the interaction among different disciplines.

Activities: A selection of news collected during the months of pandemics is proposed to be analysed. Educators guide participants in a first analysis aiming to detect: e.g., relevant questions calling for disciplinary and interdisciplinary knowledge, answers provided by the scientific communities, and analysis of the terminology used.

To introduce the IDENTITIES approach to interdisciplinarity, some videos to learn the basics of the frameworks, terminology, and tools on which the different activities of the module are built!

Introduction to the submodule (pdf, editable format)

Guide for interdisciplinary analysis of the news (pdf, editable format)

List of news (pdf, editable format)

Template for the board for the analysis of news (pdf)

Group sharing: the students report the results of their analysis on the news (vertical analysis of the board)

Group discussion: the students comment on the evolution of the news throughout time (horizontal analysis of the board)

Becoming students

Aims: The main goal of this submodule is to make participants carry out an unfamiliar interdisciplinary activity that could take place also in the classroom. The participants explore the issue of COVID-19 evolution from three different (but complementary) points of view: the real data processing, selection of variables, and their statistical analysis; the use of equation-based mathematical models for disease diffusion and the interpretation of the model's coefficients, accordingly to the data; and the implementation of an agent-based simulation using methods inspired by statistical physics to evaluate different types of social intervention.

Activities: Educators ask participants to experience an interdisciplinary project, under the role of "students of interdisciplinarity", about: (1) The complexity of delimiting the system to model: analysing data; (2) The role of the equation-based models: what can we consider a 'good' model? what are models for?; (3) Agent-based models and simulations: Simulating scenarios to help to make decisions about societal restrictions.

Introduction to the submodule (pdf, editable format)

Line 1: Analyse data to understand the evolution and formulate hypotheses (pdf, editable format)

Data of global confirmed cases (editable format)

Data of global deaths (editable format)

Line 2: The role of mathematical models in studying the evolution of the pandemic (pdf, editable format)

Data of first wave (editable format)

Line 3: Simulate scenarios to make decisions on social restrictions (pdf, editable format)

Simulation of an infectious disease outbreak - Basic phenomenon (zip folder with NetLogo file) by Xiang (2020a)

Simulation of an infectious disease outbreak - Social distancing (zip folder with NetLogo file) by Xiang (2020b)

Simulation of an infectious disease outbreak - Neighbour communities (zip folder with NetLogo file) by Xiang (2020c)

Simulation of an infectious disease outbreak - Changes in personal habits and intermittent perimeter closures (zip folder with NetLogo file and manual) by Alvarez and Rojas-Galeano (2020a, 2020b)

Simulation of an infectious disease outbreak - Population separated by age groups and geographically set (zip folder with NetLogo file) by Jimenez Romero (2020)

Group sharing

Becoming analysts

Aims: Introduction, transference, and adoption of tools for the epistemological and linguistic analysis of interdisciplinarity and of disciplinary identities.

Activities: The participants become "interdisciplinarity analysts" since, in groups, carry out a meta-reflection on the previous activity on three different levels. The first level, using the tool of questions-and-answers maps (Winsløw et al., 2013), aims to sketch the process followed through the dialectics between the specific questions that the group has faced, and the answers obtained. The second level requires recognizing in the lines of inquiry examples of boundary objects. Finally, participants analyse the kind of interaction among disciplines (i.e. boundary-crossing mechanisms) that happens when boundaries are at stake and are eventually overcome.

Introduction to the submodule (pdf, editable format)

Sketching the questions-and-answers map

Template for the first branches of the questions-and-answers map (pdf)

Sharing of findings and experiences of the groups with sketching the questions-and-answers map

Boundary analysis of the contents of the module with the second guide for interdisciplinary analysis (pdf, editable format)

Collective discussion on the interdisciplinary analysis

Becoming designers

Aims: Introduction of elements of the ecological analysis of the modules' activities to reflect on the possibilities of their transposition in schools.

Activities: In Submodule 4 some secondary school experiences linked to each line of inquiry are shared with participants. Then, they are expected to use the tools previously developed for interdisciplinary analysis to discuss the conditions to facilitate the implementation of interdisciplinary activities in real classrooms, as well as the constraints hindering the chances for interdisciplinarity to happen.

Collective discussion on the didactical transposition of the activities experienced in the module (pdf, editable format)


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

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The Module on Nanoscience and nanotechnologies

by A.Nypirakis, I. Metaxas, Ch.Bitsaki, A. Kokolaki, E. Michailidi & D. Stavrou (UoC)

Published online at: https://identitiesproject.eu/nanoscience-and-nanotechnology/

Introduction

The rationale for choosing Nanoscience-Nanotechnology (NST) for STEM teaching relies on the fact that: a) NST is by nature an interdisciplinary field, in which many disciplines interact. According to Kähkönen et al. (2016) "interdisciplinarity is the only thing that gives a name to nanoscience". In specific, physics, chemistry, biology, material science, medicine, computer science and engineering are some indicative disciplines that are related to NST phenomena. b) NST is related to many contemporary real-world applications, and breakthroughs, c) being an ongoing field of research, it gives the opportunity to students to discover new methods and new ways of thinking as well as to cultivate views of Nature of Science and Nature of Technology, and d) it can engage students in relevant socio-scientific issues and issues of responsible citizenship (Kähkönen et al., 2016; Stavrou et al., 2018).

Moreover, it is a topic that, although it is considered a contemporary advanced STEM topic, several connections with the current curricula can be used as 'entrance' points to NST concepts/phenomena/applications, e.g. atomic structure, orbitals, materials' properties (optical, electrical, etc.), polymers, etc.

The NST module makes use of theoretical frameworks implemented and elaborated during the IDENTITIES project, as follows:

1. The module uses informed views on Interdisciplinarity (Thomson Klein, 2017) both during the design of the module and the activities for the students, contrasting multi-, trans- and a-disciplinarity views.
2. The module implements the boundary object framework (Akkerman & Bakker, 2011) as a means to explore the interconnections among disciplines. Particularly, the module designers implemented boundary objects such as modelling, instrumentation and biomimicry as 'lenses' through which students would be facilitated to identify and analyse the relative disciplines and the interactions among them. Furthermore, it enacts students' epistemic agency by inviting participating students to reflect and identify additional boundary objects themselves, and also justifying their views.
3. The project also implements epistemological activators (Ravaioli, 2020) as boundary objects. In specific, epistemological activators are themes that activate a meta-level of analysis in which the disciplines can be characterised, compared and intertwined. Hence, epistemological activators can assist in the cultivation of interdisciplinary consciousness. Additionally, linguistic activators are terms, syntaxes and lexicons that can be used as another layer of identifying, comparing, and negotiating

disciplinary knowledge and skills through the commonalities and differences that they get among the languages of different communities.

4. The module implements 'professional' questions as a tool to orient students to the educational perspective and applicability of their teaching ideas. In specific, questions are been posed to students regarding the justification of introducing NST to schools, the core NST concepts to be taught, and the affordances and constraints of the transposition of NST knowledge and skills to schools.

Becoming explorers

Aims: The aim of this submodule is to contextualise NST in real-world problems and to relate it to current challenges. Significant NST applications and innovations are been introduced to students, whereas space is given to students to mention additional ones from their knowledge and experiences. The students are subsequently called upon to reflect and discuss the S-T-E-M disciplines engaged in the topics presented, and to preliminary identify boundary objects in the module in terms of concepts/methods/artefacts/questions or linguistic terms.

Activities: After a round of exploration of real-world problems that NST contributes to, the instructor(s) present some main application areas of NST, such as environmental issues, energy crisis, overpopulation and increasing need for food, healthcare and technological development. Subsequently, students work in groups and analyse the topics in the light of the disciplines involved and the boundary objects in terms of epistemological and linguistic activators in which they can identify interactions between disciplines.

To introduce the IDENTITIES approach to interdisciplinarity, some videos to learn the basics of the frameworks, terminology, and tools on which the different activities of the module are built!

Introductory presentation on NST-related real-world problems and applications (pdf, editable format)


Collective discussion on identification of NST-related real-world problems, the disciplines engaged and identification of the initial epistemological and linguistic activators (pdf,

editable format)

Becoming students

Aims: The aim of this submodule is to offer students the opportunity to get informed and to practically experience NST-related activities in some indicative main application areas. These activities act as a reference space in which students will reflect on and perform an interdisciplinary analysis in the analyst submodule.

Activities: Initially, students are introduced to core NST concepts/phenomena/applications (the 9 'big ideas' of NST). Thereafter, students work in groups in 4 sets of activities concerning: a) NST & smart housing, in which students engage with NST applications such as thermochromic glass, waterproof surfaces and self-cleaning dyes. b) NST & alternative energy sources, in which students engage with third-generation solar cells (organic & dye-sensitised dollar cells) and compare them with conventional solar cells. c) NST & Medicine, in which students explore how nanoparticles of different sizes have different energy band gaps and hence can be implemented for selective targeting of cancer cells in the human body. d) NST instrumentation, in which students engage with the main operation principles of instruments use in NST such as the Scanning Tunnelling Microscope (STM) and the Atomic Force Microscope (AFM). At the end of this submodule, time is given to student groups to recap and share their experiences with the other peer groups.

Interactive lecture on core NST concepts, phenomena, and applications (pdf, editable format)

Students explore NST applications concerning "smart" housing (thermochromic glasses & biomimetic applications about waterproofing) (pdf, editable format)

Supplementary material - Thermochromic grass (video)

Supplementary material - Lotus effect (video)

Supplementary material - Hydrophobicity (video)

Supplementary material - Biomimicry (video)

Students explore NST applications concerning 3rd-generation solar cells (pdf, editable format)

Supplementary material - DSSC (video)

Supplementary material - Organic solar cells (Smart greenhouse) (video)

Students explore NST medical applications such as the use of Au nanoparticles for cancer therapy through selective targeting (pdf, editable format)

Supplementary material - Spreadsheet (pdf, editable format)

Students explore NST instrumentation and microscopes (pdf, editable format)

Supplementary material - Surface (video)

Supplementary material - Spreadsheet (pdf, editable format)

Becoming analysts

Aims: The aim of this submodule is to introduce the theoretical frameworks for analysing interdisciplinarity, such as the epistemological and linguistic activators that act as boundary objects in this module. This submodule calls upon students to reflect on the boundary

objects implemented by the researchers in the module but also gives space to students to reflect on additional boundary objects they recognise. At the end of this submodule, students reflect on visual representations of STEM models (Ring et al., 2017) as a reflective epistemological activity on integrated STEM.

Activities: The participants become "interdisciplinarity analysts" since, in groups, carry out a meta-reflection on the previous activity in terms of reflecting on boundary objects introduced by the researchers, which were deemed to be modelling (Develaki, 2020), instrumentation (Stevens et al., 2009), and biomimicry (Krohs, 2022). Students also reflect on linguistic terms that have different nuances among communities such as 'properties', 'nanoscale', 'efficiency' and 'artificial/natural'. Furthermore, students are given the opportunity to identify additional boundary objects themselves and discuss them. Finally, students are introduced to teacher-generated STEM models (Ring et al. 2017) and are called upon to comment on them, state their preferred STEM model representation, and optionally create and justify their own STEM model representation.

Collective discussion on the epistemological and linguistic activators regarding NST concepts, phenomena, and applications students experienced in the Student block

Worksheet 1 (pdf, editable format)

Presentation - The history of the evolution of microscopes (pdf, editable format)

Worksheet 2 (pdf, editable format)

Interactive lecture on STEM integration models (pdf, editable format)

Students reflect on STEM integration models (pdf, editable format)

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

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The Module on Simulations of complex systems

by E. Barelli (UNIBO)

Published online at: https://identitiesproject.eu/simulations-of-complex-systems/

Introduction

The topic of computational simulations of complex systems was chosen because, since the 50s, they have been an authentic part of the current methodological practices in research and professional endeavours. Indeed, nowadays, in almost all disciplines, computational methods in general - and simulations in particular - are intensively used to generate knowledge and advance inquiry. In particular, computational simulations were selected because they have an interdisciplinary nature at the intersection of traditional STEM disciplines (applied physics, mathematics, and computer science of simulations) but also connect science with humanities and societal studies.

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

- the search for the connections between the physical modelling of the simulated systems, their mathematical formulation, and the computational implementation;
- the enhancement of the identity of physical modelling as a lens to describe societal phenomena, closing in this way the gap between the dichotomy of natural sciences vs social sciences;
- the emphasis on computational simulations as boundary objects i.e., artefacts that bridge different domains and trigger interdisciplinary collaboration and understanding.

Becoming explorers

Aims: The first submodule aims at a preliminary exploration of the properties of physical complex systems (non-linearity, high sensitivity to initial conditions, circular causality, emergent properties) and their educational potential.

Activities: Two dialogical lectures are proposed to participants. In the first, the instructor presents examples of complex systems (double pendulum, arctic feedback, shivering and

sweating in the human body, Rayleigh-Benard convection) to show how they embed properties that are significantly different from those of classical systems. The second lecture, instead, is focused on the research in science education about teaching and learning complexity. Specific attention is devoted to the types of explanations for emergent phenomena that novices elaborate. To make participants experience first-hand the issue, the instructor proposes them a group activity to explain the process of movement of sand dunes in the desert. After the teamwork and a collective discussion, the instructor analyses the explanation formulated by a prospective teacher engaging with the same problem.

To introduce the IDENTITIES approach to interdisciplinarity, some videos to learn the basics of the frameworks, terminology, and tools on which the different activities of the module are built!

Introduction to complex systems in physics (pdf, editable format)

Introduction to complex systems education (pdf, editable format)

Worksheet: Search for an explanation of the movement of sand dunes (pdf, editable format)

Analysis of the problem of sand dunes (pdf, editable format)

Becoming students

Aims: The main goal of this submodule is to introduce the notion of computational simulation and then to make participants experience equation-, agent- and network-based modelling and simulations by addressing specific case studies.

Activities: The submodule comprises two main interactive lectures. In the first, several definitions of simulation are discussed and two main approaches are delimited: the equation-based approach (providing the example of Lotka-Volterra model) and the agent-based one (providing the example of Schelling model). In the second lecture, the participants are led to see in action the previously delimited distinction between equation- and agent-based approaches by analysing the epidemiological model of Susceptible-Infectious-Recovered by Kermack and McKendrick; in the final part of the lecture, to these two approaches is flanked a third approach provided by network-based models to address epidemiological modelling. During the second lecture, several group activities are proposed to the participants.

Simulations of complex systems: examples of equation-based and agent-based simulations (pdf, editable format)

Equation-based, agent-based and network-based epidemiological models and simulations (pdf, editable format)

Worksheet: Extending the SIR equation-based model (pdf, editable format)

Worksheet: Exploring SIR equation-based simulation (pdf, editable format)

Worksheet: Formulating SIR agent-based model (pdf, editable format)

Worksheet: Reading SIR agent-based simulation (pdf, editable format)

Worksheet: Designing an epidemiological network (pdf, editable format)

Becoming analysts

Aims: The third submodule aims at making participants analyse from an epistemological and interdisciplinary perspective the difference between equation-, agent-, and network-based models.

Activities: Two teamwork activities are proposed to the participants to analyse the work carried out in the module so far. In the first one, the participants reflect on the comparison of the three types of models and simulations experienced; to do that, they are guided by a table with some questions (e.g. What kind of phenomena does the model allow us to deal with? What spatial and temporal structures are incorporated? What is the connection between the model and its computational implementation (in a simulation)? What allows us to visualise the simulation of models, in relation to the system to be studied?). In the second activity, the participants are asked to reflect on the boundary objects detectable in the module and the disciplines at stake. The module ends with a wrap-up that discusses the relationship between physics and the interdisciplinary field of complex systems, toward the advent of the

new discipline of computational social science that overcomes the traditional dichotomy between natural and social.

Comparing equation-, agent-, and network-based models (pdf, editable format)

Worksheet: Table for models' comparison (pdf, editable format)

Interdisciplinary analysis of the module: in search of disciplinary boundaries in simulations and complex systems (pdf, editable format)

Worksheet: Detection of boundaries and disciplinary identities (pdf, editable format)

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

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The Module on Climate change

by A. Nypirakis, I. Metaxas, C. Bitsaki, A. Kokolaki, E. Michailidi, D. Stavrou (UoC), E. Barelli, L. Miani, G. Tasquier (UNIBO)

Published online at: https://identitiesproject.eu/climate-change/

Introduction

The module concerns a theme, Climate Change, with the following features:

- The theme concerns a new STEM research field
- Physics, Mathematics, Chemistry, and Computer Science are core disciplines, although many other disciplines are involved (STE-A-M)
- The theme is educational, social, political and personally relevant and appropriate to be used within university courses for pre-service teacher education (in Physics, Mathematics and CS master courses)

For what concerns the IDENTITIES approach to interdisciplinarity, the module implements it in the following respects:

- The authenticity of **interdisciplinarity**: The module will show that there are concepts or topics related to the STEM theme, that are intrinsically interdisciplinary and cannot be reduced to the sum of S+T+E+M. *Which ones? How is the interdisciplinary - boundary zone established? When and how do you feel "inhabiting an exchange-boundary-space" and "facing the ambiguity and going out of the comfort zone"?*
- **The S-T-E-M disciplinary identities**: The disciplines have an important role in the module, as sources of structured knowledge that can nurture the development of knowledge on the STEM theme. *What roles can be attached to the disciplines and the process of disciplinarization? Are there moments where you felt particularly at home?*
- **Epistemological** and **linguistic** activators: The module includes examples of "epistemological and linguistic activators", as they will be discussed in the summer school. *What epistemological and linguistic activators do you find in the module? What makes them "epistemological and linguistic activators"?*

Becoming explorers

Aims: The goal of the submodule is to allow students to explore the concept of circular causality within climate phenomena and to allow them to delve into the construction of causal maps. Within the submodule, the concept of feedback and causal circularity are explored, aiming to show the complex nature of climate and climate change in particular. The main objectives of the activities are: i) to provide basic knowledge on causality, circularity and feedback; ii) to deliver the essential tools needed to explore the complexity of climate change; iii) to show the topic of biofuels as an example of a reality related to multiple aspects of the problem.

Activities: The aforementioned concepts and goals are explored by pre-service teachers through 2 different activities. *Activity 1) Exploring feedback in climate systems.* Pre-service teachers focus on the concept of feedback, looking at examples and videos aimed at explaining its importance, implications and possible effects on daily life. starting from the definition of climate as a complex system, the concept of causal circularity (or feedback loop) is introduced, explaining that this occurs when the change in a certain parameter influences another which in turn returns to influence the first. *Activity 2)* Reading a text on the use and production of biofuels. *Activity 3) Construction of a causal map on bio-fuels.* The activity aims to make the pre-service teachers construct a causal map on biofuels, with particular concern for biodiesel. Pre-service teachers are divided into groups of 3/4 people. At the end of the activities, three claims are analysed, and then each is followed by a question to start a discussion between all participants.

To introduce the IDENTITIES approach to interdisciplinarity, some videos to learn the basics of the frameworks, terminology, and tools on which the different activities of the module are built!

Exploring feedback in climate systems (pdf, editable format)

Reading a text on the use and production of biofuels (pdf, editable format)

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Construction of a causal map on biofuels (pdf, editable format)

Becoming students

Aims: The main goal of this submodule is to familiarise students with certain fundamental concepts of complexity in order to be able to recognise the interdisciplinary nature of complex systems such as climate change. The fundamental concepts of complexity that we explore in the student's submodule are: i) Limited Predictability in Deterministic Systems; ii) Sensitivity in the initial conditions; iii) Critical States / Feedback. The objectives of exploring the aforementioned concepts are for pre-service teachers to observe: i) the inherent limitations in predicting the evolution of a deterministic chaotic system; ii) that some chaotic systems even though they appear random yield a form of order; iii) that as a system evolves it passes through critical states that dictates its final "form" (self-reinforcement).

Activities: The aforementioned concepts and goals are explored by pre-service teachers through 4 different activities. *Activity 1)* Pre-service teachers explore the possibility of long-term predictability through the comparison of weather forecasts (7, 5, 3 and 1 day before a given date) and the actual weather conditions for the given date. Pre-service teachers are encouraged to discuss time sensitivity and the limited predictability of the weather as a complex system. *Activity 2)* It concerns the limited predictability of deterministic chaotic systems and the forms of order that non-linear systems present. In specific, pre-service teachers commented on the representations developed by a chaotic pendulum both in the case of harmonic oscillation and deterministic chaos. *Activity 3)* Critical states and their importance in the overall "form" of the system are further explored with the activity about depicting the rotation of Benard Cells. *Activity 4)* Students reflect on the ideas of limited predictability and critical states in the context of biodiesel (see explorers' section). The activity is based on a concept map about choices in the procedure of biodiesel production and the effects of such choices. In this activity, pre-service teachers recognize parts of the concept map where different choices in the production of biodiesel determine the cause of certain effects in the system.

Introduction to complexity (pdf, editable format)

Exploring the possibility of long-term predictability through the comparison of weather forecasts (pdf, editable format)

Exploring the limited predictability of deterministic chaotic systems and the forms of order that non-linear systems present through the chaotic oscillator & the magnetic pendulum experiments (pdf, editable format)

Exploring the concept of critical states through the Bernard cells experiment (pdf, editable format)

Reflection on the ideas of limited predictability and critical states in the context of biodiesel (pdf, editable format)

Becoming analysts

Aims: The main objective of the submodule is to have students analyze the topic of uncertainty in a disciplinary and interdisciplinary context, starting with the topic of climate change and then going on to generalize. The submodule focuses on the concepts of complexity and uncertainty, highlighting complexity as an epistemological activator and

boundary object, and the different types of uncertainty present within climate modelling. Specific objectives of the submodule are: i) to grasp the epistemological consequences of complexity; ii) to differentiate among the three types of uncertainty present in climate modelling; iii) to highlight the three types of uncertainties within their own disciplines of belonging; iv) to be able to generalize the three types of uncertainty and confront them in an interdisciplinary perspective.

Activities: Two activities are presented in this submodule. *Activity 1) Complexity as an epistemological activator and boundary object.* Three questions are presented to get students to think about the topic of complexity as it was seen in the previous sub-modules (explorer and student). *Activity 2) Reading and discussion on the types of uncertainty in climate modelling.* Uncertainty in climate projections arises from three sources: uncertainty in the social and political conditions that determine future climate forcing; uncertainty in our knowledge of how the climate system responds to that forcing (i.e. the change in climate); uncertainty in the actual realization of climate for a particular time window, which is subject to internal variability and to aleatory factors. Pre-service teachers are divided into three groups, one for each type of uncertainty. They are then asked to answer three questions, related to their discipline of expertise. After the 3 presentations, the instructors mediate the comparison among the groups. The pre-service teachers have to fill a scheme to meta-reflect on the perspectives opened by these issues.

Complexity as an epistemological activator and boundary object (pdf, editable format)

Reading and discussion on the types of uncertainty in climate modelling (pdf, editable format)

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

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Concluding remarks

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

The production of these modules has been methodologically framed within Design-Based Research (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003). 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 design-based research methodology has an explicit theoretical orientation (Cobb et al., 2003) that enriches the goal to design and realize good practices with the purpose of explaining why a teaching practice is more or less successful. In our specific case, the implementations have been measured in terms of modules' effectiveness to engage future teachers in practices aimed to:

a) contribute to the development of language skills, critical thinking and creativity, as well as interdisciplinary and forward-looking skills in fields that are strategic for smart economic and social development;
b) the development of conceptualization, appropriation and meaningful learning in the disciplines and the capacity to inhabit interdisciplinary boundary zones.

In order to check such validity, a plurality of data have been collected during the implementations and have been analysed through qualitative methods that include researchers' triangulation, practice reflexivity, as well as member-checking through debriefing sections at the end of the modules (with the participants of the study, that is teachers, students, researchers) (Anfara, Brown & Mangione, 2002).

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

The list of research products (papers, theses, reports, 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.
- Barelli, E. (2020). Le simulazioni computazionali come strumenti interdisciplinari di decisione: risultati di un'indagine con studenti universitari. [Computational simulations as interdisciplinary decision-making tools: results of a study with

university students]. Presented at the SIF conference – 2020, September 14th-18th (online).

- Barelli, E., Aguada, M. R., Barquero, B., Pipitone, C. (in preparation). Investigating the interdisciplinarity of COVID-19 through the identification of boundary objects: a module for pre-service STEM teachers.
- Barelli, E., Barquero, B., & Branchetti, L. (under review). Questioning the evolution of the pandemic in an interdisciplinary way: the design of a Study and Research Path for pre-service Teacher Education. *Rivista Matematica dell'Università di Parma*.
- Barelli, E., Branchetti, L., & Barquero, B. (2021). Questioning interdisciplinarity within teacher education: A module on the evolution of COVID-19 pandemic. Presented at the 14th International Congress on Mathematical Education (ICME), July 12-19 2021, online.
- Barelli, E., & Levrini, O. (2021). Scientific Simulations as Educational Tools for the Post-Pandemic Era: the Case of the Susceptible-Infectious-Removed Model. Presented at National Association for Research in Science Teaching (NARST) International Conference, 7-10 April 2021.
- Barelli, E., & Levrini, O. (2022). Navigating micro and macro levels of agent-based simulations to build analogies with real-world issues. In G.S. Carvalho, A.S. Afonso & Z. Anastácio (Eds.), Fostering scientific citizenship in an uncertain world (Proceedings of ESERA 2021), Part 8 (co-ed. Antti Laherto and Eliza Rybska), (pp.631-640). Braga: CIEC, University of Minho. ISBN 978-972-8952-82-2.
- Barelli, E., & Levrini, O. (2022). Computational simulations at the interface of physics and society: a teaching-learning module for high school students. *Il Nuovo Cimento C*, *45*(6). doi:10.1393/ncc/i2022-22213-6
- 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).
- Barquero, B. (2022). Los Recorridos de Estudio e Investigación en contextos STEM: su diseño y análisis ecológico. *Invited plenary lecture at Encuentro Internacional sobre la Enseñanza del Cálculo, Ciencias y Matemáticas* (Septiembre 2022).
- Barquero, B., Barelli, E., Romero. O., Aguada Bertea, M. R., Jimenez, J., Pipitone, C., & Sala Sebastiá, G. (2021). Teacher education for interdisciplinarity: design of a module about modelling coronavirus evolution. *Presented at European Science Education Research Association (ESERA) Conference*, August 31-September 3 2021, online.
- Levrini, O., Branchetti, L., Stavrou, D., Barquero, B., & Durand-Guerrier, V. (2021, August 30-September 3). *IDENTITIES: Integrate Disciplines to Elaborate Novel Teaching approaches to InTerdisciplinarity and Innovate pre-service teacher Education for STEM challenges.* [Poster presentation]. European Science Education Research Association (ESERA) Conference, Braga.
- Nipyrakis, A., Kokolaki, A., Michailidi, E., Giannakoudaki, K., Metaxas, G., Kapelonis, N., Dimitriadi, K., Stavrou, D. (2021, November 19-21) *Η διεπιστημονική STEM προσέγγιση στην Τριτοβάθμια Εκπαίδευση: Το πρόγραμμα IDENTITIES. [The interdisciplinary STEM approach in Higher Education: the IDENTITIES programme].* [Poster presentation]. Πρακτικά 12ου Πανελλήνιου Συνεδρίου Διδακτικής των

Φυσικών Επιστημών και Νέων Τεχνολογιών στην Εκπαίδευση, Αθήνα. [Proceedings of the 12th National Conference of Science and Technology Education, Athens]

- Bitsaki, C., Stavrou, D. (2022, September 16-18). Διερεύνηση των Διασυνδέσεων STEM πεδίων σε διδακτική ενότητα Νανοτεχνολογίας από μελλοντικούς εκπαιδευτικούς [Pre-service teachers investigation of STEM integration between STEM disciplines in a teaching module on Nanotechnology]. Presented at the 4th National Young Researchers' Conference of Science and Technology Education - 2022, Alexandroupoli. (Under publication)
- Bitsaki, C., Nipyrakis, A., Metaxas, I., Kokolaki, A., Michailidi, E., Dimitriadi, K., Stavrou, D. (2022, May 13-15). Διεπιστημονικές STEM διασυνδέσεις σε διδακτική ενότητα Νανοεπιστήμης – Νανοτεχνολογίας [STEM integration in a teaching module on Nanoscience-Nanotechnology.] Presented at the 1st International Conference of Department of Primary Education, University of Ioannina - 2022, Ioannina.
- Michailidi, E. (2022, November 5). Mapping contemporary STEM teaching: Towards an integrated interdisciplinary approach. [Round table presentation]. 12th National conference "Preschool science education" held in Florina, Greece. https://12sece.nured.uowm.gr/
- Nipyrakis, A., Kokolaki, A., & Stavrou, D. (2020, July 10). IDENTITIES project: Novel Teaching approaches to Interdisciplinarity for STEM Challenges. Presented at the 6th International Scientific Conference of the Institute of Humanities and Social Sciences – 2020, Heraklion.
- Nipyrakis, A., & Stavrou, D. (2020, August 27-29) *Προσεγγίσεις Εν Ενεργεία Εκπαιδευτικών Β/θμιας Εκπαίδευσης κατά τον Σχεδιασμό & Ανάπτυξη STEM Διδασκαλιών σε Πλαίσιο Κοινότητας Μάθησης (In-Service Teachers' Approaches on the Design & Development of STEM Teaching in a Learning Communities Framework).* Πρακτικά 3ου Συνεδρίου Νέων Ερευνητών για τη Διδακτική των Φυσικών Επιστημών και Νέων Τεχνολογιών στην Εκπαίδευση, Θεσσαλονίκη (διαδικτυακά) (Proceedings of the 3nd Conference of New Researchers in Science and Technology Education, Thessaloniki (online)).
- Nipyrakis, A., Stavrou, D., & Avraamidou, L. (2022, March 27-30) *In-Service Teachers' Views about STEM Integration: A case study.* [Poster presentation]. National Association for Research in Science Teaching (NARST), Vancouver.
- Nipyrakis, A., Stavrou, D., & Avraamidou, L. (2023, April 18-21, accepted). *Interdisciplinary Pre-service Teacher Training.* [poster presentation] National Association for Research in Science Teaching (NARST), Chicago.
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- Vásquez, S., Barquero, B., & Bosch, M. (under review). A Study and Research Path about the Evolution of Pandemics at Secondary School: Conditions for an Interdisciplinary Approach. *Rivista Matematica dell'Università di Parma*.
- Vásquez, S., Barquero, B., & Bosch, M. (2021). A Study and Research Path about the Evolution of Pandemics at Secondary School: Conditions for an Interdisciplinary

Approach. *Proceedings of the Twelfth Congress of the European Society for Research in Mathematics Education (CERME12), Feb 2022, Bozen-Bolzano, Italy. ffhal-03758988f*

The main results are:

a) the effectiveness of the approach to explore the interdisciplinary nature of STEM advanced topics (Michailidi, 2022), where the roles of the disciplines have been valued. This aspect has fostered both deep engagement of the participants and the activation or development of systemic and critical thinking (Barelli, 2020; Barelli & Levrini, 2001a; 2001b);
b) The effectiveness of the boundary metaphor to set up a safe and stimulating interdisciplinary zone in which mechanisms of learning at the boundary can be recognised and consciously activated;
c) The fruitfulness of the construct of boundary objects that pre-service teachers are able to recognize when they are coming across with the interdisciplinary nature of nanotechnology and to use for inhabiting an interdisciplinary zone (Bitzaki, 2022; Bitsaki et al., 2022);
d) The effectiveness of interdisciplinary artefacts like simulations to foster the development of future-scaffolding skills (Barelli, 2022);
e) The fruitfulness of the perspective of complexity to provide the language to navigate the uncertainty and the ambiguity of wicked problems (Miani, Stavrou, Levrini, in progress).

Because of the richness of the data collected, further analyses are ongoing and the results will be presented at future conferences and published in research papers.

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