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Eleonora Barelli, Berta Barquero
and Laura Branchetti

Questioning the evolution of the pandemic in an interdisciplinary way: the design of a Study and Research Path for pre-service Teacher Education

Abstract. In this paper, we present the main objectives, the framework and one example of a module developed within IDENTITIES, an Erasmus+ project for higher education addressing the general goal to innovate mathematics, physics, and computer science pre-service teacher education in an interdisciplinary direction. The design of the module we present, on the topic of modelling the evolution of the pandemic, is grounded on the proposal of the study and research paths for teacher education (SRP-TE), but, since the goals of the activities were oriented to trigger questions and meta reflections about interdisciplinarity, the development of the module itself induced an evolution also in the SRP-TE structure and tools. The present analysis shows the main innovations made to properly deal with interdisciplinary aspects of the topic and the critical issues that emerged when the paradigm of "questioning the world" was applied to a topic at the boundary between different disciplines.

Keywords. Interdisciplinarity, Anthropological Theory of the Didactic, pre-service teacher education, modelling, COVID-19.

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1 - Introduction

Interdisciplinarity (ID) is a keyword appearing nowadays, often with different meanings, in many institutional and educational contexts and populating policy recommendations at both national and international levels. This concept is also at the basis of the STEM approach to education that strongly promotes integration between scientific theoretically oriented forms of knowledge and applications, with the aim to foster the development of skills that are becoming more and more relevant in contemporary societies. In the beginning, the reflections were more addressed to rethinking discipline-based traditional curricula and good practices, while in the last years the need for a theoretical reflection on integrated STEM education [**12**] has been stressed by different educational research communities (e.g. *ERME* - European society for Research in Mathematics Education, *ESERA* - European Science Education Research Association, *NARST* - USA National Association for Research in Science Teaching) and papers in educational research journals (e.g. *Science and Education*, *International Journal of STEM Education*, *Canadian Journal of Science, Mathematics and Technology Education*). In this favour, we have several examples of major issues in our society that require a collective scientific effort working across the boundaries of the scientific disciplines. This work is framed within the European project IDENTITIES (www.identitiesproject.eu) which addresses the issue of ID in secondary pre-service teacher education in mathematics, physics, and computer science, developing both materials and a common approach to mixing and integrating different theoretical perspectives in mathematics, physics, and computer science education [**3**].

In this paper we show an adaptation of design principles of activities for teacher education, developed within the mathematics education community, to turn them into new design tools for interdisciplinary pre-service teacher education. In particular, we extensively refer to the Study and Research Path for Teacher Education (SRP-TE) [**4**], framed within the Anthropological Theory of the Didactic (ATD) [**9**]. Given the fundamental role of models and modelling in the understanding and social dissemination of the pandemics, we present our experience with the design of an SRP-TE about decoding the evolution of the COVID-19 pandemics, targeted at prospective secondary school teachers enrolled in master's programmes in physics, mathematics, or computer science education, attended by participants with different disciplinary backgrounds [**19**]. Specifically, we are interested in addressing the following research question concerning the design and analysis of the module: *RQ1: What traits does the instructional proposal have in order to promote interdisciplinary reflections among prospective teachers and educators? RQ2: Which questions*

and tools encourage the questioning about ID?

We focus on how the module was designed to make the prospective teachers discover firsthand the contribution of mathematics, physics and computer science, and their intertwining, in different phases of the evolution of the pandemic. Moreover, we aimed to value the participants' disciplinary background in their exploration of the problem, guiding them to make more and more explicit their disciplinary perspectives, in dialogue with colleagues with different expertise. Narrating the module's design, we clarify the innovative aspects of the interdisciplinary adaptation of the SRP-TE, and, in the last section, we highlight the main features of such a module that can become design principles for similar pre-service teacher education activities.

2 - Theoretical Framework

In this section, we present the two-pronged framework at the basis of the module's design and of the IDENTITIES project at large.

2.1 - *The SRP-TE within the paradigm of questioning the world*

Within the framework of the anthropological theory of the didactic (ATD), a change in school paradigm [**9**] is proposed to overcome some of the main didactic phenomena linked to the "monumentalization" of the knowledge to be taught. This change has been described in terms of a paradigm shift, from the "paradigm of visiting works" to the "paradigm of questioning the world" [**9**]. Chevallard characterizes the transformation in mathematics education not only at the pedagogical level ("how to teach?") but also includes a paradigm shift on the didactic level ("what and how to teach?"). In the paradigm of questioning the world, the knowledge to be taught is associated with the study and inquiry into relevant questions. The study of these questions includes moments of study (searching for available answers in the media) and moments of inquiry (deconstruction and reconstruction of knowledge to generate one's answer). Implementing question-led study processes helps the knowledge to be taught to become dynamic, provisional, and collective (compared to the traditional notion of knowledge in school institutions).

In the ATD, some investigations have used the teaching devices called *study and research paths* (SRP) that have been introduced to facilitate the inclusion of mathematical modelling in educational systems and, more importantly, to explicitly situate mathematical modelling problems at the centre of teaching and learning practices [**6**]. More recently, our research team have been working

on the proposal of *study and research paths for teacher education* (SRP-TE) [**4**], an inquiry-based process combining practical and theoretical questioning of outside and inside school scientific activities in the particular context of teacher education. This approach is then characterized by: i) the formulation of questions about the teaching profession that are rich and relevant enough to be placed at the heart of pre-service teacher education programmes; ii) the facilitation, through the collective inquiry into these questions, of epistemological and didactic analysis of knowledge at stake.

2.2 - *A framework to articulate the relationship between disciplines and ID*

For a definition of ID, we rely on Klein [**13**] that sees true ID as a combination of integrating, interacting, linking, focusing, and blending. The adaptation to interdisciplinary cases has been carried out relying on some elements of two different frameworks relevant to ID: i) the Reconceptualized Family Resemblance Approach for the Nature of Science (RFN) [**10**], which problematizes the notion of *discipline* and the relationships between scientific disciplines in terms of *resemblance and idiosyncratic features*, and ii) the boundary objects and boundary-crossing mechanisms [**1**], that shape the dynamics of interaction and highlight the learning mechanisms that are necessary to bridge knowledge and practices of different communities.

The RFN framework [**10**] addresses the methodological problem of defining science by avoiding a definitory approach and including both the diversity of the scientific disciplines and their reciprocal resemblances. The features that characterize a discipline are organized into a structure composed of a cognitive-epistemic and a social-institutional system. In particular, the cognitive-epistemic system is articulated in 4 categories: aims and values, methods and methodological rules, practices, and scientific knowledge. The first three categories can be used to stress the aspects that guide scientific practices that are common to different disciplines, as well as to discuss different approaches in order to make visible that, even flexible and context-dependent, boundaries between different disciplinary approaches exist [**17**]. The fourth category refers to knowledge as a network where theories, laws and models are related and that are products of collaboration to which every scientist contributes by bringing a point of view but also discussing with other experts [**22**]. This view is far from a representation of knowledge as discrete and disconnected fragments belonging to different disciplines. Debate, discussion and awareness of one's own point of view are thus at the core of the development of scientific knowledge. The shift to such a view of science as a network and of boundaries as tools to make the differences visible is crucial to designing activities where

prospective teachers with different backgrounds question the world together, guided by questions that encourage them to exploit their personal disciplinary resources and knowledge.

To foresee difficulties and good strategies to make the collaboration fruitful, the lens of boundary objects and boundary-crossing learning mechanisms (BO/BCLM) can be effective [**1**]. Indeed, boundary objects are understood as the "objects that enact the boundary by addressing and articulating meanings and perspectives of various intersecting worlds" (p. 150). The boundary-crossing mechanisms describe types of interaction between disciplines activated by shared practices, that produce mutual learning and allow to become aware of personal perspectives (identification), develop new tools to address common problems (coordination), understand deeply the others' perspectives (reflection) and, finally, rethink one's own point of view thanks to the interaction with the others (transformation). Satanassi and colleagues [**17**] showed that sharing with prospective teachers the key points of this framework might help them to create suitable boundaries and become more aware of their personal point of view, orienting them in interdisciplinary practices, in pre-service teacher education contexts.

In this paper, we exploit the RFN and BO/BCLM to enrich the SRP-TE approach in order to make prospective teachers aware of the potential and criticalities of ID in secondary teaching. Relying on our framework, we identified abilities that should be developed by prospective teachers in order to design and manage interdisciplinary modules at the secondary school level. In particular, we recognize three main needs: i) the need for tools for the epistemological analysis of ID (RFN); ii) the need for common terminology to refer to and to analyse ID (BO/BCLM); iii) the need for tools to question the conditions and constraints under which interdisciplinary can be transposed into schools (RFN).

To provide prospective teachers with such tools, we carried out an epistemological analysis of the different contributions of disciplines and their intertwining in specific cases in order to grasp the main points to address and we looked for a common approach to teacher education in the case of teachers with different backgrounds working together. To pursue these goals, frameworks and methodological approaches to teaching and learning in secondary school developed within the disciplinary communities (mathematics, physics, and computer science education) have been not only combined but also enriched and enlarged in order to address the challenges posed by ID. The process of restructuring and adaptation also involved existing approaches to pre-service teacher education and were carried out in deep collaboration between experts in different fields, who co-designed interdisciplinary modules addressed to future teachers.

3 - Design of the SRP-TE about the COVID-19 evolution

We present a study focusing on the design of an instructional proposal for prospective secondary school teachers based on an adaptation of the structure of the SRP-TE, focusing on the *role of models and modelling to the understanding of the COVID-19 evolution* with an approach intertwining mathematics with other STEM disciplines. We recognize in this case an authentic example of STEM advanced ID requiring educational interdisciplinary research. Indeed, the natural disciplinary interactions that we can often observe in scholarly practices outside school, such as research activity in mixed disciplines, mathematical ecology or epidemiology, among others, are hard to be transposed into school.

The COVID-19 pandemic has shown more than ever that students and, more in general, citizens need to understand how mathematical and scientific advances contribute to understanding societal phenomena. In addition, "the pandemic illustrates perfectly how the operation of science changes when questions of urgency, stakes, values and uncertainty collide" [**16**]. More than ever, people felt the need to understand what mathematical models can provide, how we may interpret the predictions and, more generally, how they help understand complex systems such as the pandemics' evolution.

Nevertheless, there is no doubt about the critical constraints that hinder the dissemination of interdisciplinary activities in school institutions. They can be interpreted because of the prevalence of important didactic phenomena that exist in school institutions, such as the isolation of disciplines and the prevalence of monodisciplinary curricula, the dominant way to organize the teaching and learning of school disciplines, more based on the logic of concepts rather than the logic of addressing questions or problems. On the opposite, as Michelsen argues [**15**], "the challenge is to replace the current monodisciplinary approach, where knowledge is presented as a series of static facts disassociated from time with an interdisciplinary approach, where mathematics, science, biology, chemistry and physics are woven continuous together" (p. 269).

In the case of the pandemic, the modelling tools and the knowledge embedded in the simulations used to create scenarios about its evolution were not belonging only to mathematics, but to understand them and their contributions it is necessary also to include agent-based simulation and to consider deeply the computational aspects of modelling. Moving from a disciplinary to an interdisciplinary exploration of the topic is thus very significant from the epistemological point of view. Moreover, since experts of many disciplines discussed scientific issues, also in public debates and in newspapers, in most cases it emerged that the use of different languages created a kind of Babel where it

was hard to follow the thread of the global discussion about the pandemic. This social phenomenon showed the need for a deep reflection on the meaning of the terms used and it made necessary the development of a common language to talk about such complexity. The topic was thus rich and relevant enough to consider it as a case of ID to explore in pre-service teacher education.

This adaptation of the general structure of the SRP-TE [**5**] has consisted of four submodules, where participants had to assume different roles to facilitate questioning together (prospective teachers with educators) the way to describe, analyze and design possible modelling activities that could be transposed to secondary schools. All module's resources (worksheets, datasets, presentations) are published online and freely available on the IDENTITIES website [**14**].

In Submodule 1, participants are asked to act as "explorers" to analyse a set of news and research dissemination papers that the educators had selected to see the evolution of the problems addressed by the scientific community and to analyse the role assigned to the disciplines. From this first analysis, participants with educators delimit some possible "lines of inquiry" that involved models and modelling and the interaction among different disciplines. The topic addressed in each line were: (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?*; and (3) *Agent-based models and simulations: simulating scenarios helping decisions about societal restrictions.*

Submodule 2 asks participants to experience a teaching activity, previously designed by the educators, about the above-mentioned lines of inquiry. Participants are asked to assume the role of "students". The main goal of this module is to make participants carry out an unfamiliar activity that could, to a certain extent, exist in an ordinary secondary school classroom. Moreover, another aim was to create a shared context, an experimental *milieu* (in the sense introduced by Brousseau [**7**]) among prospective teachers and educators.

In Submodule 3 the participants carry out a collective analysis of the activity experiences as students, now playing the role of "analysts". Two main tools were introduced to help prospective teachers analyse the activity carried out: i) the *questions-answers map* (Q-A map) [**21**] which aimed to support the students in making explicit the issues addressed by identifying questions posed and answers reached and ii) the *guide to interdisciplinary analysis* that asked the participants to recognise in the previously encountered activity possible boundary objects and the different types of boundary-crossing mechanism [**1**].

Finally, in Submodule 4, prospective teachers start working on the design of an adaptation of the teaching activity they experienced in Submodule 2.

4 - Methodology

In this paper, we are interested in analysing the instructional proposal's main traits that aim to promote interdisciplinary reflections among prospective teachers and educators. Moreover, we focus on analysing the kinds of questions and tools that have been planned to be transferred to prospective teachers to question, discuss and construct a common understanding of ID.

With this purpose, we anticipate two kinds of questions that were proposed in the module to trigger interdisciplinary reflections on the topic of the module. The first are *topic-specific questions* (TSQs) which are strictly related to the issue under study - in our case, the evolution of the COVID-19 pandemic. Examples of questions are: *How can we characterize the evolution of COVID-19 in Spain or in Italy in 2020? What can be done to make the vaccination campaign against COVID-19 effective? Which factors account for the differences in terms of cases incidence among the neighbourhoods in a city?*. The second type is *meta-reflection questions* (MRQs) that aim to trigger a deeper reflection about the ID that emerged when addressing the TSQs. In the case of the MRQ, we distinguish between two types of questions. The *epistemological MRQs* focus on the level of identifying the disciplinary contributions as well as the ways in which disciplines interact and the necessary dialogue that might be settled between them at the epistemic level [**10**]. Examples of questions are: *How have the different disciplines contributed to the societal understanding of the evolution of COVID-19? On which levels have the disciplines interacted by facing this challenge? Are there disciplines more legitimated to address some particular questions than others? Have the disciplines changed through their interaction? How to analyse this interaction?*. The second type of MRQs is represented by the specifically didactic ones that aim to trigger a deeper reflection on the conditions and constraints that can favour or, on the contrary, can hinder the transposition and dissemination of interdisciplinary practices in school institutions (in particular, into secondary school institutions) involving TSQs. We name them *ecological MRQs* in the sense introduced by Chevallard [**8**] (see also [**4**] in the case of teacher education) since they aim at questioning the constraints that can prevent an interdisciplinary project to be viable and sustainable in classroom practice. In addition to that, they aim to dig deep into the necessary conditions to be set up in the classroom for interdisciplinary to be well established. Examples of questions are: *What limitations can existing curricula establish to design and implement interdisciplinary practice? What is the role of teachers of different subjects? What common terminology about ID (or more in concrete, about models, modelling, virus propagation, etc. in our case) might be shared by teachers and students to progress properly in the*

implementation of an interdisciplinary project?.

In this paper, we use these different "categories" of questions to articulate the narration and analyse the design of the module for prospective teachers, highlighting how different dimensions – the conceptual, epistemological, methodological, and didactical – are covered in the design of the submodules of the SRP-TE. The design we focus on was developed by researchers in mathematics, physics and computer sciences education at the University of Barcelona and the University of Bologna. This module was then adapted for its implementation in a Summer School of the IDENTITIES project with a mixed group of 12 prospective secondary school teachers in mathematics, physics and computer science from Spain, Italy, Greece, and France, under the guidance of the researchers-designers (from now on we will refer to them as "educators"). In the following section, we analyse the design of the module, not going into the results of its implementation, but analysing the driving questions guiding its design and implementation under the above-mentioned conditions.

5 - How the questions supported the interdisciplinary inquiry throughout the module

5.1 - *Posing meta-reflection questions to orient the gaze*

At the beginning of the module, before entering the specific activities of the submodules, three overarching questions are introduced by the educators to the prospective teachers:

MRQep01) How have the STEM disciplines interacted to investigate the evolution of the COVID-19 pandemic? What answers have been given and how have their advances spread to society?

MRQep02) What role does ID play and how can we analyze it when addressing complex issues related to the evolution of the COVID-19 pandemic?

MRQeco01) How can the interdisciplinary practices that took place during the COVID-19 pandemic be transposed and diffused to secondary schools?

According to the characterization provided in the section above, they can be labelled as meta-reflection questions since they relate to the specific topic of the module (the evolution of the COVID-19 pandemic) fostering prospective teachers' reflection on issues regarding the ID of the topic. These questions allow establishing, from the beginning, the pillars that build the scaffolding

on which the prospective teachers will conduct their work in the module: the relationship between the individual STEM disciplines and the interdisciplinary context; the societal character of the issue at stake; the educational perspective. They are authentic open-ended questions, in the sense that admit a plurality of answers. On these questions, the students will have the chance to work in the following parts of the module, through activities that will pose more specific, refined - hence addressable - questions.

5.2 - *The search for topic-specific questions to facilitate the initial discussion on ID*

In Submodule 1, the participants, assuming the role of "ID-explorers", are asked to explore a set of news and research dissemination papers previously selected by the educators. The activity aims at addressing mainly the first overarching question (MRQep01). Indeed, reading the news, the prospective teachers are asked to identify: i) the main questions addressed by the scientific community, ii) the STEM disciplines mentioned, iii) the answers provided, iv) the tools and disciplinary knowledge that allowed them to obtain these answers, v) the specific terminology used in the text. The aim of this activity is, on the one hand, to guide the prospective teachers to identify TSQs that the scientific community had been addressing and, on the other hand, to provide a preliminary answer to MRQep01, detecting the roles of the disciplines (by themselves or connected to each other) in contributing to this discussion.

The pieces of news were selected by the educators in a way that a multiplicity of TSQs could be recognized by the participants. Indeed, some articles explicitly address "how many"-questions, covering quantification issues related to the numbers of the pandemic: *How many cases were recorded in Spain in 2020? How many people have died so far because of COVID-19? Which European countries were hit the most in the early phases of the pandemic?*. In other types of news, "what/how"-questions can be identified regarding issues of description related to the nature of the disease: *What is the reproduction number of the coronavirus? What is the infectivity of the disease? What happens to asymptomatic individuals? What protection do vaccines provide?*. The third kind of TSQ, recognisable in many pieces of news, is that of "why"-questions that were connected to issues of explanation of phenomena or behaviours: *Why do the curves of infected individuals follow an exponential trend? Why can we expect other waves of the pandemic?*. Finally, also "what to do"-questions are addressed in the news, linked with issues of decision-making: *Which behaviours do models suggest limiting the pandemic spread? Who should we test? Should we vaccinate the elders or the people with more contacts first? Should we trust*

the predictions of models and simulations?.

The reader could notice that the mentioned types of TSQs, that the participants are expected to recognize in the pieces of news assigned, can easily overlap: for example, issues of explanation can be easily merged with issues of description, and the same happens with the questions related to quantification and those connected to decision-making. Our *a priori* identification of different types of questions, rather than delimiting boundaries, is aimed at leading students to recognize a plurality of questions that were addressed during the pandemic by researchers, professionals, and societal actors at large. We also want to underline that, even if the TSQs are more delimited with respect to the MRQs, most of them are anyway related to ID. In all the examples we have provided in the previous paragraph, answering the TSQs requires moving across different disciplinary STEM domains, from the mathematical modelling through differential equations to the statistical characterization of data, from the computational dimension of simulations to the biological accounts of phenomena. In this sense, passing through the identification of TSQs in the pieces of news, the prospective teachers could recognize that many STEM disciplines contributed to the debate about the COVID-19 pandemic and that they did not act in restricted disciplinary boundaries but contaminated one another. All these elements can contribute to address other epistemological questions (like MRQep01).

5.3 - *Addressing TSQs under the role of "ID-student"*

In submodule 2, the participants are asked to become "ID-students" to investigate the issue of COVID-19 evolution following three complementary lines of inquiry that are opened by three "big" TSQs:

TSQ1) How may COVID-19 data be organized to be statistically analyzed?

TSQ2) How can mathematical models (like Gompertz's and SIR model) help fit, interpret data, and make predictions?

TSQ3) How can agent-based models and simulations help to compare and analyze the impact of different political interventions?

These questions were *a priori* chosen by the educators, considering the news that the participants had read in the previous phases and with the goal of including three different types of approaches that have been used by the scientific community for the study and sense-making of the pandemic: the statistical analyses to extract relevant information from data, the development of mathematical models to make predictions, and the elaboration computational

simulations to understand virus diffusion and provide information to policy-makers. In the next paragraphs, we show how a plurality of questions guided the participants' work in each line of inquiry, in the search for the disciplinary and interdisciplinary perspectives on the topic.

5.3.1 - Statistical models to analyze the evolution of the pandemic

At the beginning of their work, the students involved in the first line of inquiry are suggested to access data and graphics about the pandemic worldwide, to explain what information they embed and their potential. They are asked to start from three issues as examples of possible TSQs that can be addressed through statistical techniques of data analysis, from visualizations to correlation measures: *What was the evolution of COVID-19 in Asia in 2020? What differences can be found between different countries? Which has been the effect of the vaccination process?*. On the basis of these prompt questions, the students freely explore given datasets, formulate some hypotheses about the evolution of the pandemics, and identify other derived questions to address.

5.3.2 - Mathematical models to predict the evolution of the pandemic

The participants in the second line of inquiry start their work by addressing a very general TSQ related to the role of models in the context of COVID-19: *What is the role of models and modelling in investigating the evolution of COVID-19?*. To unpack the different issues involved in this question, other, more specific, questions are proposed as prompts for the students' inquiry: *What does it mean to model some data? What is a model? What would be a "good" model for understanding the evolution of COVID-19? What are the goals of modelling data? What are we studying when we model the actual data on the evolution of COVID-19?*. Accessing, fitting and testing datasets, the students are guided to explore different equation-based models to fit and predict the evolution of the pandemic. In particular, they study to what extent the exponential law expressed by Gompertz's model accounts for the evolution of the infected population's size in the early stages of the epidemic and allow them to derive sensible predictions.

5.3.3 - Agent-based models to make decisions to mitigate the effect of the pandemic

In the third line of inquiry, the participants encounter NetLogo agent-based computational simulations [**20**] and explore how they help model COVID spreading, elaborating and comparing scenarios for societal restrictions, and supporting decision-making processes. The generative TSQ that guides the participants since the beginning is: *How can computational simulations support decision-making processes about future actions in the context of the pandemic (from political, economic, medical, etc. perspectives)? What are their validity and function?*. Throughout the activity, agent-based models of increasing complexity are proposed to the prospective teachers. They were encouraged to address and outline TSQs to focus at first on the qualitative models at their basis and proceed up to the investigation of the details of their computational implementation. Examples of TSQs are: *How is social distancing embedded in the simulation? How do different degrees of social distancing impact the results? What happens when borders between neighbourhoods are maintained versus when borders are removed? How different communities are "coded" in the simulation?*.

5.4 - *Mapping TSQs and analyzing their interdisciplinary character through MRQs*

After participants finish addressing (under the role of students) the questions related to their line of inquiry, they are asked to describe the activity followed by the construction of what is called the question-answer map [**21**]. Through this tool, the participants can make explicit the questions they have addressed (generating and derived questions) and the answers achieved. Since all the groups are given the same virtual space to draw their Q-A map, the participants have the opportunity to look at the issues addressed by the others and were encouraged to establish connections (in the questions addressed or in the tentative answers provided) across the lines of inquiry. Previous investigations in the framework of the ATD have been working with the Q-A maps as epistemological tools for the analysis of the knowledge at stakes, both at the school level and in teacher education ([**21**], [**11**]). The aim of this analysis was to break with the usual way of describing disciplinary contents - which usually prioritises concepts, notions and techniques to the detriment of questions and problems - without using complex terminology. It enabled the participants to change the order of priorities, highlighting the dialectic between questions and answers in the activity they had followed.

The core of the interdisciplinary analysis of the module starts with the second part of Submodule 3 when the prospective teachers, working in mixed groups (so that at least one member of each line of inquiry was present in each group) become analysts of the interdisciplinary experience done in the module. The aim here is to contribute to providing an answer to the second overarching question of the module (MRQep02). The framework that explicitly guided the formulation of the questions proposed to the participants in this phase was Akkerman and Bakker's meta-theory on the concept of boundary, summarized in the previous section, that they had already encountered during the summer school. The first MRQ requires the participants to discuss the boundary objects encountered during the module:

MRQep1) In light of the activities carried out, what are the boundary objects (questions, answers, methods, techniques, concepts, etc.) that can be identified in the module? Why?

The students, sharing their experiences in the different lines of inquiry, are expected to focus on issues at the interface of different disciplines, like the very same idea of the epidemiological model itself that can be seen as a mathematical object as well as a physical, biological, and computational one. The request for *identification* - in Akkerman and Bakker's terminology - of the disciplines contributing to the interdisciplinary work with boundary objects becomes more explicit with the following question:

MRQep2) What disciplines can you identify in the activities you have experienced? What has been the role of each one? What tools and insights have these disciplines contributed to the overall theme of the module?

For example, when addressing these questions, the students have the opportunity to highlight that, in the modelling practices with which they have engaged in the different lines of inquiry, applied physics is needed for modelling the real system (on the basis of the knowledge coming from medicine, infectiology, or biology), mathematics is essential for writing and interpreting the differential equations in the case of the Gompertz' model, while computer science allows the implementation of the mathematical model in a functioning algorithm; moreover, when decision-making issues are addressed, the role of social sciences can also be pointed out. After having recognized the disciplinary identities at stake in the module, the third MRQ pushes them a bit further, toward reflecting on how the disciplines *coordinate* when dealing with the interdisciplinary issue of understanding the evolution of the pandemic:

MRQep3) How would you describe the relationship that has been established between the disciplines involved in the module? Are there problems or issues in which the type of knowledge coming from a particular discipline has been sufficient to advance? On the opposite, what problems or issues have required knowledge from different disciplines and their interaction? What were the points that opened the need for disciplinary interaction?

This three-pronged epistemological question creates the context for prospective teachers' meta-reflection on the relationship between disciplines in the specific activities experienced in the module. For example, the participants could discuss that, when it comes to analyzing the components of mathematical equations or the value of parameters, or determining which computational function is best suited to write the code, the reasoning can remain within a single discipline. On the other hand, when comparing different types of approaches to model and predict the evolution of an epidemic, such as the equation- and agent-based ones, a dialogue between the disciplines can be observed [**2**]. In specific phases of the module, the relationship between disciplines is not limited to cooperation in addressing a common boundary object, but feedback on the disciplinary practices themselves. This is the case of the boundary-crossing mechanism of *reflection*, on which the next MRQ focuses:

MRQep4) Regarding the issues that have required the interaction of disciplines, what changes can be observed between the role of each discipline in this interdisciplinary context and the role traditionally assigned to them in schools or universities?

This question is aimed at making the students point out that comparing different approaches to modelling the spread of an epidemic is a way to view the disciplines in a less stereotypical way. For example, a key concept is that of probability, which appears differently in the parameters of the equations of Gompertz's model (experienced by the prospective teachers in the second line of inquiry) or in the behavioural rules of the agent-based simulations (embedded in the NetLogo simulation that the participants in the third line encountered). Focusing on examples concretely experienced in the module, the participants can go beyond some flattened disciplinary delimitations that school teaching often encourages: in an interdisciplinary topic, disciplines are nurtured by confrontation with others and generate new knowledge. Unveiling the novel type of knowledge that emerges from ID and that eventually generates new practices that *transform* the disciplines themselves is the objective of the last MRQ that deeply connects with MRQep1, in which boundary objects have to be detected:

MRQep5) What new knowledge and new interdisciplinary practices have been established thanks to the interaction between disciplines on this topic?

At the end of their work as analysts of ID, the prospective teachers are now in the position to look back at the idea of epidemiological models. Indeed, the modelling practice itself can be interpreted as an interdisciplinary practice, with its own characteristics that go beyond the characteristics of the disciplines taken individually.

5.5 - *Going back to classroom practice through MRQs*

The didactical and ecological dimensions, opened at the beginning of the module with the third overarching question (MRQeco01), constitutes also its closure. Indeed, in Submodule 4, the students are asked to adopt the new role of "teachers at secondary school" and to meta-reflect on the activities carried out in order to identify the facilitating conditions or the constraints that could support or prevent the transposition of similar interdisciplinary activities in secondary school education. The discussion is supported by posing the following ecological MRQ:

MRQeco1) Which questions, through which activities, could be transposed into secondary school education? Which opportunities or conditions would be offered that facilitate this transposition towards secondary school? Which difficulties, limitations or constraints would hinder or could prevent the implementation of the inquiry into these open questions in secondary schools?

In the particular adaptation and implementation of the module in the IDENTITIES Summer School, mentioned above, Submodule 4 could not be addressed in depth. However, ecological MRQs become central when working on the redesign, adaptation, and analysis of the interdisciplinary activities for secondary school education, as, in this issue, Vásquez and colleagues argue [**18**]. In any case, starting to approach this kind of questions with teachers in training allows them to start sharing and collecting the first institutional limitations or constraints that participants can already anticipate when interdisciplinary activities are planned to be transferred to secondary school (under the adoption of the role of "teachers"). When such a discussion is undertaken, there are often constraints of different scopes that are shared, e.g. lack of time, rigid curricular boundaries between disciplines, the dominant conceptual disciplinary elements, and poor collaboration between subject specialists, among others. As explained

in [**4**], the aim is to underline that these obstacles are not individual, they have to be understood as institutional constraints that can be situated at different levels of specificity (e.g., of the disciplines' content organisation) and generality (e.g. the way that secondary school curricula organise the school disciplines, or how our society, more in general, defines the disciplines and their possibilities of interaction). Starting to recognise them is the first step towards becoming collectively aware of their existence and highlighting the need for robust epistemological and didactic tools to address the issue of ID and the role of different disciplines when they are transported to secondary school classrooms.

6 - Discussion and conclusions

In this contribution, we have shown how interdisciplinary questions have guided the design of an SRP for pre-service teacher education on the topic of modelling the COVID-19 evolution. In our analysis, we were guided by two research questions. We recall each of them to summarize the main results achieved.

RQ1: What traits does the instructional proposal have in order to promote interdisciplinary reflections among prospective teachers and educators?

This module is an example of interdisciplinary SRP-TE, where the main innovations, due to the inclusion of ID, are oriented by our framework for ID (mainly built on RFN and BO/BCM) and have the goal to characterize from a disciplinary perspective the prospective teachers' exploration of the problem without coming to a separation into independent activities. Moreover, the activities designed pursue the goal to trigger discussions that have as an output the development of prospective teachers' awareness of their disciplinary point of view and of the significantly different perspectives of people with another disciplinary background, identifying and respecting the aims and values and the useful constraints imposed by a disciplinary view.

RQ2: Which questions and tools do encourage the questioning about ID?

We have identified two different types of questions: *topic-specific* and *meta-reflection*. While, for what concerns MRQs, the connection with ID is explicit, this is not the case with TSQs. However, the TSQs are planned to be approached before, when participants engage in an activity to create a rich *milieu* between prospective teachers and educators to then look again at their experience with "new glasses" for the analysis of ID. MRQs are asked, in the module, to foster boundary-crossing mechanisms like identification ("What are the disciplinary contributions to the definition of the epidemiological models?"), coordination ("How can the shared concept of model establish a communicative connection between the disciplines involved?"), reflection ("Has the interaction

among the disciplines at the boundary enriched the disciplines?") and transformation ("Has the disciplines' interaction on epidemiological models contributed to establishing novel interdisciplinary modelling practices?").

Considering the two RQs together, we can discuss at a broader level the potential of questioning for interdisciplinary pre-service teacher education. The questions we formulated aim not only to make the participants explore a problem and involve them in a rich experience, where they can use their knowledge to deal with societal issues but also to make sense of their mutual differences in their ways of dealing with the same issue. This way they can learn something more general about disciplines and their relationships, that can scaffold their future interdisciplinary approach to such topics at school. As we stressed, this change of perspective - from sharp boundaries to an interdisciplinary "architecture" with common topics and many overlaps - is one of the most difficult aspects of ID, and a guide is necessary in order to make it explicit and exploit the learning potential [**1**]. The main aspects of innovation, that can be turned into design principles for future interdisciplinary SRP-TE are: to find open-ended questions admitting a plurality of answers; in the case of TSQs it is important that the possible answers can overlap and oblige to moving across different disciplinary STEM domains, as in the case of the pieces of news, where it is not possible to find restricted disciplinary boundaries but all the STEM disciplines contaminated one another; encourage students to address clear and meaningful epistemological questions (like MRQep01) emerging from the case they are investigating.

For future development of this work, we started investigating the delicate passage from pre-service teacher education to secondary school teaching. Indeed, observation of prospective teachers moving to real secondary school contexts is necessary to investigate whether and how teachers who participated in interdisciplinary SRP-TE can effectively transpose such activities to school environments, and to look for other possible obstacles emerging when they collaborate with teachers with different disciplinary backgrounds in a discipline-based context. The paper by Vásquez and colleagues [**18**] goes in this direction: indeed, the first author participated as a prospective teacher in the summer school and, after having experienced the module, designed her own adaptation of the module and implemented it in a secondary school classroom. Vásquez led the design and implementation of an SRP which was conducted together with secondary school teachers of different subjects (mathematics, biology, physics, technology, and communication). This collaboration contributed to delving into the problematic issue of creating conditions and detecting constraints that hinder the implementation of interdisciplinary practices in schools. In particular, the work points out that these constraints can derive from the school and

the delimitation of school disciplines into subjects, from the curricula, from the lack of collaboration among teachers from different backgrounds, or from the need for new tools and culture of ID to be set up between teachers and with students [**18**].

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ELEONORA BARELLI
Department of Physics and Astronomy "Augusto Righi"
Alma Mater Studiorum - University of Bologna
Via Irnerio, 46
Bologna, 40126, Italy
e-mail: eleonora.barelli2@unibo.it

BERTA BARQUERO
Department of Linguistic and Literary Education, and Teaching and Learning of Experimental Sciences and of Mathematics
Universitat de Barcelona
Passeig de la Vall d'Hebron, 171
Barcelona, 08035, Spain
e-mail: bbarquero@ub.edu

LAURA BRANCHETTI
Department of Mathematics "Federigo Enriquez"
University of Milan
Via Saldini, 50
Milan, 20133, Italy
e-mail: laura.branchetti@unimi.it