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Interdisciplinary task design for pre-service teacher education: learning potentials at the boundary between mathematics and physics

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We present and discuss a pre-service teacher education sequence aimed at promoting professional development on interdisciplinarity. The sequence of activities is conceived around two main ideas: to use textbooks as a source of reflection, and to progressively guide students towards a theory-informed analysis of textbooks. Here we present the analysis of the first step of the sequence, highlighting two learning potentials that emerged during the class discussion in one implementation.

Keywords: Preservice teacher education, teacher education, interdisciplinary approach, awareness.

Introduction and background

In this paper, we present and discuss the first step of a pre-service teacher (PT) education sequence that aims at promoting professional development on interdisciplinarity (ID) between mathematics and physics, both as a goal itself and as a means to promote PTs’ awareness about their conceptions of the disciplines (Satanassi et al., 2023).

The relationships between mathematics and physics are often conceived in a trivialized way, even in the literature on mathematics and physics education: mathematics is assumed to be a tool for calculation in physics, while physics is presented as a context for the application of mathematical techniques (Karam, 2015). This representation attributes to mathematics an *instrumental* role in physics, whereas the analysis of authentic scientific practices and historical resources shows that it often plays a *structural* role (Udhen et al., 2012). Scholars have stressed the different uses of mathematical objects in physics teaching and learning; for instance, Serbin and Wawro (2022) observed the inextricability of mathematical and physical reasoning. At the institutional level, a preliminary study on teaching practices was carried out by Castela (2017), who showed differences between mathematical practices tout-court and mathematical practices in physics. These studies problematize the idea of an instrumental role for mathematics in physics, whereas, as emphasized by several authors and summarized in Branchetti and colleagues (2019), the relationship between the two disciplines is much richer, thanks to their mutual co-evolution and contamination in teams where different experts collaborate closely.

One of the most critical aspects of ID teaching approaches is the notion of discipline itself, and its impact on the relationship between knowledge and the representation of knowledge as a map with clear boundaries between different domains. The Family Resemblance Approach (FRA) to Nature of Science (Erduran & Dagher, 2014) allows to characterize “disciplinary identities” both in terms of epistemological status (namely, as forms of organizing knowledge, practices, methods, and a range of unique individual cognitive skills) and in terms of aims and values, considering the nuances of

interaction between people, individually or within institutions, and not just objects and techniques (Satanassi et al., 2023). In the FRA, the epistemic core of a discipline thus consists of four related components: *aims and values* (like objectivity, consistency, rigor, etc.), *practices* (like explaining, arguing, representing, etc.), *methods* (like generating reliable evidence and construct theories, laws, and models), and *knowledge*. The institutional “disciplinaryization” of knowledge exacerbates the features of the instrumental paradigm, leading to the creation of separated communities, habits, and values, rather than exploiting the productive ambiguity of the dialectic between the identity of each discipline and the dynamics of family resemblances. Ideal boundaries between disciplines are built to clearly separate the objects and practices belonging to each discipline in the secondary school, leading to the dominant metaphor of “exchanging” products from one community, as might happen in a trade, and using them to solve problems in the other community (Satanassi et al., 2023). Considering our specific case of the role of mathematics in physics, such a narrative might suggest that mathematical objects, techniques and epistemic practices are borrowed from mathematics as they are and that the “correct” use of such tools is the same in mathematics and physics. For instance, in the case of parabolic motion, the main idea might be as follows: the parabola is first created as a product in mathematics class, and then it is used in physics to model the motion of a projectile.

We are interested in addressing the above-mentioned themes in the context of teacher education, in which we rely on the idea of teacher professional development presented by Mason (1998, 2002) as “becoming more expert” (Mason, 2002, p. 1), as a process towards an “expert” perspective:

[expert mathematics teachers] not only have mathematical expertise, but they are also aware of the nature of that expertise, and they have ways of re-entering the state of not having that expertise. (Mason, 1998, p. 243)

According to Mason

it is essential to keep refreshing the heuristics, the sensitivities and awarenesses which make up that discipline, in order both to be stimulating for students, and to be sensitive to their experiences. (Mason, 2002, p. 208)

Our research aim is to explore ways to promote teachers’ awareness about interdisciplinarity issues.

In this perspective, we also refer to Akkerman and Bakker’s characterization of the four mechanisms that allow crossing the boundaries, in our case, between mathematics and physics: *identification* occurs when a deep uncertainty about the boundary between disciplines leads first to questioning the core identity of the intersections and then to new perspectives on the disciplines; *coordination* occurs when cooperation between disciplines is required to maintain the flow of work and the use of common tools; *reflection* occurs by explaining and understanding the differences between disciplines, and thus enriching their identities; and *transformation* leads to a profound change, and even to new and intermediate disciplines (Akkerman & Bakker, 2011).

A first attempt to design teacher education activities with a focus on ID was carried out by Pollani and Branchetti (2022) in the context of a mathematics education course involving master students in mathematics. A key feature of the teaching intervention was the use of a physics textbook. Interest in textbooks has gradually increased within the mathematics education community, especially in recent

studies on curriculum development (Pepin, 2016). As recognized by Pepin and Haggarty (2001), textbooks relate to the intended curriculum and have a strong influence on the taught curriculum. Recognizing the crucial role of textbooks and considering them as representatives of the institutional way of presenting the content to be taught, in Pollani and Branchetti (2022) the physics textbook was used as a source of reflection on mathematics, physics and ID. Discussing and writing may lead PTs to cross boundaries and increase their awareness; hence, we introduced the following construct:

the terms *disciplinary* or *interdisciplinary learning potential* [refers to] the increasing awareness respectively about disciplines, conveyed by *identification* and *reflection*, or of their interplay, conveyed by *coordination* and *transformation*. (Pollani & Branchetti, 2022, p. 426)

Their data analysis showed that the PTs analyzed extracts from the physics textbook implicitly assuming the “universality” of the values that characterize mathematics, without showing any awareness of this. This study highlighted the need for careful task design in PT education to make participants aware of their disciplinary perspective and, in FRA words, of the values, practices, methods, and knowledge of mathematics and physics.

In this contribution, we present the refined task design, still based on the idea of using textbooks as a source of reflection on mathematics, physics and ID.

Design of the intervention

To promote professional development and make teachers aware of specific issues related to ID in a long-term intervention, we have designed a teacher education sequence around two main ideas: to use textbooks as a source of reflection on mathematics, physics and ID, and to progressively guide PTs towards a theory-informed analysis of textbooks. The sequence is described as follows:

Phase 0: PTs get to know a theoretical tool (Habermas’ construct of rationality; see Morselli & Boero, 2010) and use it to analyze the process of proving in mathematics.

Phase 1: PTs read and compare two extracts from two physics textbooks: first they discuss in pairs or small groups, and then they share their thoughts in a class discussion. As PTs are not explicitly asked to use a theoretical tool for the comparison, we will refer to this phase as the “naïve phase”.

Phase 2: PTs are explicitly asked to analyze the two extracts using the theoretical tool of rationality, which we posit act as a scaffolding factor (Pollani & Branchetti, 2022). We will refer to this phase as the “scaffolded, or not naïve, phase”. Again, first PTs discuss in pairs or small groups, then they share their thoughts in a class discussion.

The teacher education sequence was carried out in the context of a course in mathematics education during the academic year 2021-2022. The course is offered to those students enrolled in a master’s degree in mathematics who are interested in becoming teachers of mathematics and/or physics for upper secondary schools (grades 9-13). In this paper, we will refer to them as “pre-service teachers” since they are following a curriculum focused on teaching and they have little or no previous teaching experience. It is important to note that these students will have to pass a selection after the master’s degree to be certified to teach secondary school mathematics and/or physics.

For this implementation, we selected extracts from two high school physics textbooks on the same topic: parabolic motion (Walker, 2010, pp. 79–80; Ruffo & Lanotte, 2016, pp. 232–233). Bagaglini and colleagues (2021) showed the interest in this topic from an epistemological point of view by analyzing different presentations in Italian textbooks and a historical edition of Galileo’s original book, highlighting key disciplinary and interdisciplinary aspects that potentially provide opportunities for teachers to address the topic not only per se but as a key example from an epistemological point of view. Moreover, some features of the textbook presentation (choice of examples, representations, linguistic features of the text, etc.) revealed the author’s implicit assumptions about the relationship between mathematics and physics and the identities of the disciplines (Bagaglini et al., 2021).

Mason’s construct of expertise and awareness defines the long-term goal of our teacher education programme. We are asking whether it is possible to promote awareness about ID, and we are investigating the viability of a specific teacher education activity using textbooks. We ask ourselves:

- What do PTs observe during the naïve phase? Can these observations be read in terms of *learning potentials* (Pollani & Branchetti, 2022)?
- To what extent do PTs reflect as *expert teachers* (Mason, 2002) during the naïve phase?

Method

We refer here to the naïve phase of our implementation, which involved five PTs (pseudonymized here as PT1, ..., PT5) and during which the three authors acted as teacher educators. The class discussion was video recorded and transcribed. Each author performed a separate qualitative analysis of the transcript, commenting on the students’ interventions according to two dimensions (learning potential and extent of reflection). This analysis was based on our previous a priori analysis of the textbooks which led us to identify two main themes that could have conveyed *learning potentials* (namely, instrumental vs. structural ID and representations). We then shared the qualitative analysis to reach a mutual agreement. The result of this process is presented here.

Results

Below we present some of the PTs’ observations during the class discussion of the naïve phase, organized around the two learning potentials.

The instrumental vs. structural interdisciplinary learning potential

In the first excerpt from the discussion, referring to the textbook sentence “It is possible to prove that the horizontal displacement, called the *throw*, is proportional to the product of the velocity components” (Ruffo & Lanotte, 2016, p. 233), PT1 claimed:

PT1: A thing I’ve always suffered from, will be for me, is giving formulas and saying, ‘It is possible to prove that’ and here it is. Well, it depends on... maybe the teacher integrates it, maybe the students [...] already know all they need to know about parabolas [...] and then it’s fine. But maybe, if it’s a first... let’s say if I don’t know anything [...] and I’m reading it, I don’t understand so much... let’s say that.

PT1 refers to the way formulas are usually presented in textbooks: such a habit, in her view, may hinder non-expert readers in the structural perspective of explaining and understanding (Karam, 2015,

p. 491) about formulas to a more technical calculating and describing view. PT1 speaks from the (future) teacher's point of view as she mentions and cares about how (future) students might approach this text. The perspective of formulas as mathematical tools in physics can be further elaborated and developed to allow the blossoming of an interdisciplinary learning potential.

In the next excerpt from the discussion, after sharing his (recurrent) perspective on considering (and distrusting) the preparation of future students, and therefore assuming the (future) teacher's perspective, PT2 begins a rough reflection on knowledge:

PT2: I always wonder what the level of their [*he refers to students who must read here say the first presentation*] preparation might be. Done well the uniform motion and the uniform accelerated motion, the second... the formula, especially that of the free-falling object, should not be frightening so much [...] I also, as PT1 said, don't like the 'it is possible to prove that' thing so much [...] so I would not trust whether the students know the properties of a parabola, the two formulas or not. There are more important concepts which are the vertex of a parabola and the point where the parabola cuts the x-axis.

PT2 focuses more on the domain-specific (mathematics) *knowledge* part of the epistemic core of the disciplines, in the sense of the FRA (Satanassi et al., 2023), considering concepts as the vertex and the x-intercept, while he does not mention, for example, the *practice*, in the sense of the FRA, of modelling (either in mathematics or in physics).

The interdisciplinary learning potential concerning representations

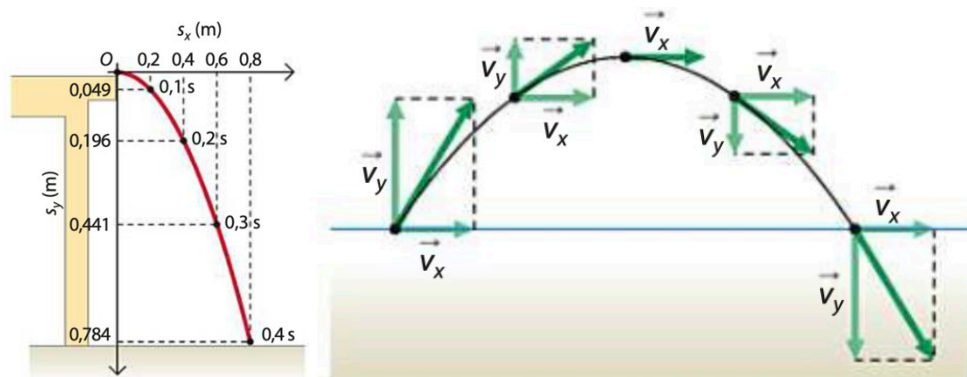


Figure 1: Left picture from Ruffo & Lanotte (2016, p. 232), right from (ibid., p. 233)

The following extracts from the discussion deal with the issue of representations in the textbook, particularly concerning pictures and tables.

PT2: I liked the drawing [*see the right picture in Figure 1*] [...] I think it is quite detailed [...] It is schematic [...] figures are very useful because [...] they motivate: having a story, maybe step by step, of... something can help, I think. [...]

PT3: At the top, that figure [*see the right picture in Figure 1*] with the velocity vectors as well, then what I liked about this book is that it puts this figure on the left [*see the left picture in Figure 1*]: the text explains exactly how to construct the axes, precise references are given; so, it is less up to the student to interpret.

PT2: The only trauma I thought the student might have, is suddenly finding the origin at the top [...] protests that it's nice because there's the axis going up, the axis going right, the origin, where do you put it? [...] Wait, but shouldn't there be negative values below zero? And so, they might suffer.

The “usefulness” of figures is justified by PT2 in terms of increased student motivation and by PT3 in terms of easing the cognitive resources required, while a general interest in figures emerges, conveyed by a general sense of “schematics”. We note that while in the first intervention, PT2 takes the university student’s perspective, it is less clear how to describe PT3’s perspective in this intervention, as she talks about what she likes (thus, we may refer to the university student’s perspective), but she also mentions the “student”, so there is probably a coexistence with the (future) teacher’s perspective. The last intervention of PT2 is from the (future) teacher’s perspective, as he mentions a possible trauma of (future) reading students. Furthermore, he explicitly refers to drawings and the choice of the reference system; this discourse can also be interesting for the instrumental vs. structural interdisciplinary learning potential, as the reference system seems to be an “external” tool mechanically borrowed from mathematics (Satanassi et al., 2023). This mechanicity also takes along mathematical expectations on the graph, such as the position of the origin and the direction of the axes. The domain-specific (physics) epistemic core is not considered (Satanassi et al., 2023).

TABELLA 1					
t (s)	0	0,1	0,2	0,3	0,4
s_x (m)	0	0,2	0,4	0,6	0,8
s_y (m)	0	0,049	0,196	0,441	0,784

Figure 2: Table from Ruffo & Lanotte (2016, p. 232)

- PT4: We liked the figures, also the table [see Figure 2] in the second text. [...]
- PT5: As PT4 said, the table is very nice in the sense that it shows that each time corresponds to a coordinate on the x and y axes, and then how the movement of the projectile is represented and the different drawings. We like the drawings, both the one with all the tangent velocities [see the right picture in Figure 1] and then the one at the bottom where it shows that the parabola varies depending on the angle of the initial velocity [see Figure 3].

Here we can see another general interest in images, as some PTs focus on the correspondence between time and coordinates and the dependence of the parabola on the launch angle. We recognize the university student’s perspective and, again, the fact that only these ways of using and praxes, borrowed from mathematics, emerge, while the domain-specific (physics) epistemic core remains hidden (Satanassi et al., 2023).

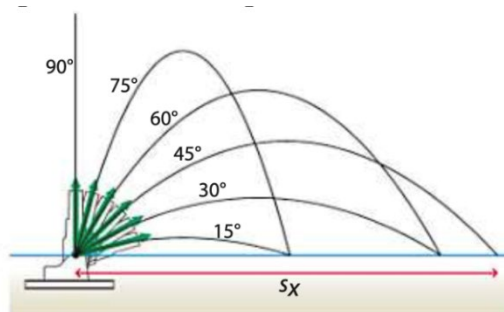


Figure 3: Picture from Ruffo & Lanotte (2016, p. 233)

Discussion and preliminary conclusions

In this contribution, we presented and discussed the first step of a teacher education sequence aimed at promoting professional development on ID. After detailing our design choices, we analysed relevant excerpts from the class discussion to address the following questions:

- What do PTs observe during the naïve phase? Can these observations be read in terms of *learning potentials* (Pollani & Branchetti, 2022)?
- To what extent do PTs reflect as *expert teachers* (Mason, 2002) during the naïve phase?

Concerning “what” PTs observe, we reported interventions that may be ascribed to two interdisciplinary learning potentials: one referring to the duality instrumental vs. structural ID, the other one referring to the role of representations. Concerning the level of reflection as “expert teachers”, we noted two main perspectives adopted by PTs in their textbook analysis: on the one hand, some of their interventions reveal the perspective of themselves as university students; on the other hand, when they mention (future) students, what students need to know, how students might feel, they adopt the perspective of the teacher. This duality of perspectives reflects the delicate transition from being a university student to being a high school teacher (second transition) and manifests itself as a duality of voices, even within the same PT. Moreover, we wonder whether the levels of the described PTs’ reflections on textbooks may be conceived as forms of Mason’s *noticing*: “To notice is to make a distinction, to create foreground and background, to distinguish some ‘thing’ from its surroundings” (Mason, 2002, p. 33). He distinguishes three forms of *noticing* other than *not noticing*: *perceiving*, when “sufficient memory is established accessibly to be jogged and reconstructed by what someone else says”, *marking*, when “not only do you notice but you can initiate mention of what you have noticed”, and *recording*, when, through inward or outward records, “you might choose to re-mark at some future moment”. This is a promising perspective, that needs to be further elaborated, and that could help us in conceiving our long-term intervention. We plan to continue with the analysis of the second phase of the long-term intervention, to see what is added when the PTs are required to undertake a theory-informed analysis of the textbooks.

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