INTERDISCIPLINARITY IN SPECIAL RELATIVITY: DEVELOPMENT OF ACTIVITY FOR PRE-SERVICE TEACHER EDUCATION

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ABSTRACT

From a historical point of view, mathematics and physics are closely related and interconnected fields of knowledge. However, the division present in academic and scholastic worlds leads to a separation of knowledge that limits the ability to develop a comprehensive view that grasps the important commonalities and boundary aspects. Special relativity can be taken as an example to highlight the deep connections between the two disciplines. This paper presents an activity, reserved for pre-service mathematics and physics teachers, based on an analysis of the mechanisms of boundary crossing between the two disciplines within the theory. This work highlights how specific and well-detailed attention to these mechanisms can shed light on nuances that are very important in enabling learning about the multifaceted nature of Lorentz transformations.

1 The IDENTITIES project

The society in which we live is deeply marked by a profound interconnection between different areas of knowledge. Thinking about issues we face daily, such as artificial intelligence, bioengineering or climate change, we realise how these problems cannot be addressed from a unique point of view (NSC, 2013). A sectoral and mono-disciplinary education cannot prepare one for the challenges of today and tomorrow. For this reason, for a couple of decades now, several international research groups have been focusing on interdisciplinary research areas, creating opportunities and providing funds to invest in research that goes beyond the delineated boundaries of individual disciplines (EC, 2021; NRC, 2013).

The work we present in this paper is related to one of these projects, the IDENTITIES project (Integrate Disciplines to Elaborate Novel Teaching Ap-

proaches to InTerdisciplinarity and Innovate pre-service Teacher Education for STEM challenges, https://identitiesproject.eu/), in which it is assumed that the search for the meaning of interdisciplinarity cannot do without the meaning of disciplines and their epistemological identities. The project aims to create interdisciplinary, innovative and transferable teaching modules and courses to be tested and used in teaching training contexts, with a focus on the connections between physics, mathematics and computer science.

2 Interdisciplinarity and Special Relativity in Science Education

In the research area of physics education, many studies have focused on the connection between the disciplines of mathematics and physics, as they have always been deeply interconnected (Ataide & Greca 2013; Branchetti, Cattabriga, and Levrini, 2019; Pospiech, 2014). However, the disciplinary separation that occurred around the last century has led to epistemological, conceptual and practical issues that are reflected in the outcomes and knowledge learned by students. Indeed, many works in the literature focus on the difficulties students have in combining concepts and tools from the two disciplines and the difficulties teachers have in preparing courses or lessons that touch on both (Levrini & De Ambrosis, 2010; Margot & Ketler, 2019), or how the underlying reasoning belonging to the two disciplines leads to the creation of profound differences between the two (Rédei, 2020).

To address these issues, some authors have used a historical perspective to highlight the deep ties that bind the disciplines, e.g., Galili (2018) or Tzanakis (2002; 2016). Using a history-pedagogy-mathematics/physics (HPM/Ph) perspective, Tzanakis has analysed and explored the links between the two disciplines from a historical and epistemological point of view, highlighting how the use of practical examples of exchange and collaboration that occurred at the historical level can bring out the deep interconnection present between mathematics and physics. Using the Special Theory of Relativity (STR) as one of these examples, he focused on the differences in the approaches and backgrounds between Lorentz, Poincaré, Einstein, and Minkowski (Tzanakis, 2016).

In the physics education literature, STR has been studied from many different aspects, from conceptual change (Hewson, 1982; Posner et al., 1982; Scherr et al, 2001, 2002) to historical reconstruction (Levrini, 2002; Darrigol,

2006; Jankvist & Kjeldsen, 2011) or students' difficulties (Alstein, 2020; Guisasola, 2009; Tanel, 2014,). One aspect lacking from the literature, however, is an analysis that demonstrates the potential for learning at the boundary between disciplines, that is, one that focuses on the learning potential that an interdisciplinary view can bring for students.

Our work builds on other works already done in analysing original papers on the Special Theory of Relativity in which, through the use of a framework to highlight the mechanisms for crossing the boundary between disciplines (Akkerman & Bakker, 2011), the deep interconnections between the two and the different perspectives of the authors themselves are highlighted (Miani, 2021; Miani, 2022). These works were then carried forward through the construction of an analysis grid that allowed, through an iterative process of analysis and comparison of results, to highlight approaches peculiar to the individual disciplines to the general theme, and how these approaches succeed in highlighting different aspects of the same concept or tool, in particular Lorentz Transformations (Modica, 2022; Miani, Modica, Levrini, in progress).

Here we present the design and the implementation of an activity realised to focus on these approaches and the theoretical procedures used by the original authors (Lorentz, 1904; Poincaré, 1906; Einstein, 1905; Minkowski, 1908) to demonstrate their aims.

2 Activity design

The activity is based on a work of analysis and critical reading of 4 texts fundamental to the emergence of STR (Miani, 2021; Modica, 2022). The analysis of the texts aims to highlight the boundary-crossing mechanisms between disciplines applied by the authors. Each author has a very different background, approach and method of explaining and using mathematical tools. The lens developed in Modica (2022) allowed us to emphasize these mechanisms, highlight patterns of boundary crossing, and mark each article according to a different reasoning process. These results have been then used to guide the activity proposed to the students.

For the lesson, excerpts concerning the topic of Lorentz transformations were selected. The reason these were chosen is that, from the analyses conducted, they can be seen as a boundary object, as they provide different points of view and take on different facets depending on the perspective (or discipli-

nary approach) from which they are viewed. To contextualize the excerpts, Lucia prepared presentations of 5 minutes each to introduce the different papers and the intent of each of the 4 authors.

38 students took part in the activity, of which 9 had a mathematical background and 29 a physics one.

In the previous lectures, the class had already approached STR from different perspectives (e.g., its historical evolution, the way it has been proposed in school, and the different teaching approaches with which it can be taught within the field of physics education).

3 Activity development

The activity is divided into two parts (two lessons of 3 hours each): in the first lesson, a presentation was made on the concept of boundary, presenting it from both an etymological and a social/historical point of view. after that, students were asked, through the use of a Wooclap, to present what they thought were the reasoning procedures peculiar to the disciplines of mathematics and physics:

- In your opinion, which proceedings do you recognise as being proper to or characterising disciplines such as mathematics or physics?

After everyone discussed these together, they moved on to the general presentation of the articles, on which the students then worked for the rest of the first lesson in 9 groups of 4/5 students each. At the end of the first lesson and the beginning of the second, the groups returned the answers given to the questions that had been posed as the delivery of the analysis activity, namely:

- What is the procedure (or procedures) that distinguishes each author?
- In your opinion, does such a procedure belong to mathematics, physics or both? and why?

Once all the opinions had been collected, we presented to the students the methods and results of our analysis conducted through the implementation of the grid based on Akkerman and Bakker's boundary-crossing mechanisms. following this presentation, we then carried on a discussion of about an hour in which we discussed the potential that a study such as the one just presented could bring compared to a general analysis without lenses such as the one carried on by the students themselves in the first lesson.

4 Results and discussion

As a result of the first question, 89 responses were received (Fig. 1). The responses can be viewed in detail in Modica (2022, p. 123). In general, what is evident is the presence of a general and at times stereotypical view of what mathematics and physics can be and their character traits.

Figure 4. Wordcloud representing the main procedures in mathematics and physics (obtained through wooclap.com)

About the analysis of the texts, it is noticeable how the students' analysis brought out the different processes peculiar to each author, but without being able to find distinct features among the four. Instead, the lens developed through the framework on boundaries succeeds in naming these processes, and distinguishing and defining them. The ability to name these procedures allows one to develop a clearer view of the approaches and intents of the different authors, thus enabling a deeper understanding of their reasoning mechanisms.

5 Conclusions

Special relativity plays a key transitional role between classical physics and modern physics. The construction of interdisciplinary activities such as the one presented can help to first understand the dynamics of the theory's development among different disciplines and the roles they can play in providing insights into the theory's content. In addition, this kind of activity allows one to extrapolate and name those mechanisms intrinsic to the disciplines that are often applied unconsciously but encapsulate the very epistemological essence of the disciplines, through which deeper and more multifaceted knowledge can be achieved.

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