A META-DISCIPLINARY REFLECTION ON A STEAM SCHOOL ACTIVITY: THE ROLE OF MATHEMATICS

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This paper aims at providing a meta-disciplinary reflection on the role of mathematics in the design of a STEAM activity for lower-secondary schools. The analyzed case study involves a group of teachers of different disciplines from the same Italian school, who collaboratively designed an interdisciplinary STEAM activity, following a template created by researchers in mathematics education, in the context of an international European project. We analyze data gathered in an interview with the mathematics teacher of the group, conducted to gain insight into the role of mathematics in the design of the activity, from her point of view. Different roles emerged from the teacher's reflections about the subsequent phases of the project, entailing an evolving relationship between mathematics and the other disciplines.

INTRODUCTION AND THEORETICAL BACKGROUND

Interdisciplinarity indicates an approach to a topic that embraces the competences of different scientific sectors or disciplines, which cooperate to provide a wider understanding of a common topic (Capone, 2022). More than 50 years ago, at the Seminar on Interdisciplinarity in Universities held in Nice (France), scholars joined efforts to promote interdisciplinarity and identify the role of mathematics in interdisciplinary activities, reckoning that interdisciplinarity "is important to allow students to find themselves in the present-day world, to understand and criticize the flood of information they are deluged with daily" (Apostel et al., 1972, p. 14). This becomes even more relevant today, in a world that increasingly demands intertwined skills to make sense of its complexity. Indeed, interdisciplinarity in mathematics education (Doig et al., 2019) and in STEAM (Science, Technology, Engineering, Arts and Mathematics) education (Khine & Areepattamannil, 2019; Henriksen, 2019) has been assuming increasing importance in the last decades. Yet, Piaget warns us that, due to its deductive nature, mathematics has a "particular independence" (Piaget, 1972, p. 127) from other scientific disciplines of experimental nature. This peculiarity requires a focused effort by the teachers to make interdisciplinary connections between mathematics and other disciplines apparent to students.

Researchers in mathematics education in many parts of the world implement "various sorts of conjunction of mathematics with other knowledge" (Williams & Roth, 2019). In these implementations, the role of mathematics is interpreted in different ways (Stohlmann, 2018). Sometimes, mathematics is conceived as a tool for doing the computational work needed to solve scientific/technological problems; in other cases, mathematics is used to model phenomena observed in other disciplines (Williams & Wake, 2007).

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The aim of this paper is to conduct a *meta-disciplinary* (Williams & Roth, 2019) reflection on the role of mathematics in the design of an interdisciplinary STEAM activity for lower-secondary schools, based on how it is perceived by the mathematics teacher as a co-designer of the activity. Addressing this issue, we can contribute to deepening the insight into interdisciplinary STEAM teaching and collaborative design of STEAM activities by teachers of different disciplines. Our research question is: What is the role of mathematics in a STEAM activity, cooperatively designed by teachers of different disciplines, according to the mathematics teachers' perspective?

CONTEXT AND METHODOLOGY

Our study context is the Erasmus+ Project named STEAM-Connect, where researchers from different countries (Austria, Finland, Italy, Luxembourg and Slovakia) and teachers of different disciplines (arts, mathematics, music, technology, etc.) work collaboratively to design STEAM activities for all school grades. Different levels of connection are expected as outcomes of the project: a connection between teachers of different disciplines in each school, between teachers of different schools in the same country; between researchers and teachers of the same country, between researchers from different countries, and between researchers and teachers from different countries during the dissemination phase. We claim that the process of designing an interdisciplinary STEAM activity is far from trivial. It takes a long time and multiple design cycles for teachers to learn how to collaborate and coordinate to choose a common object (a problem or a topic) and to pursue the common aim of the activity.

The STEAM-Connect project has a duration of three years and started in November 2021. During the first months of the project, researchers from all the involved countries co-created a common template for the STEAM activities to be designed by teachers. The common template had the aim of supporting the exchange, sharing and dissemination of the STEAM activities within different schools, in the same country or in different countries, in the final phase of the project.

The data analyzed in this paper refer to the Italian national phase of the project, in which the teachers used the template provided by the researchers to collaboratively design STEAM activities. For our investigation, we selected as a case study a lower-secondary school in Piedmont, open to educational innovation and already engaged with the Mathematics Department of the University of Turin (UNITO) in other projects. Firstly, we analyzed the template filled in by the teachers of this school to gain an overview of the STEAM activity in terms of involved disciplines, school grade, time needed and learning objectives. Then, we conducted a semi-structured interview with the mathematics teacher of the school, Paola (pseudonym), who is a very experienced teacher, having also the role of teacher-educator in other projects. She answered two main questions, which constituted the baseline of the interview: 1) "How did the idea of the STEAM activity that you designed in your school come about?"; 2) "How would you describe the role of mathematics in the STEAM activity that you designed in your school?"

With a qualitative methodology and an interpretative approach (Cohen et al., 2007), we analyzed the transcript of Paola's interview, to answer our research question, with specific attention to the evolution of the role of mathematics in the design of the STEAM activity during the project, as described by Paola.

RESULTS

From the first part of the template designed by the researchers (Figure 1, translated from Italian by the authors), filled in by Paola and her colleagues to describe their STEAM activity, we understand that it is intended for a sixth-grade class and it deals with the topic of symmetries and translations. The involved disciplines are: arts, music, technology, science and mathematics. Among the learning objectives, the teachers declare a general objective, common to art, music and science, which refers to the real-world applications of the concept of symmetries and translations. Besides that, they declare a learning objective specific to mathematics, connected with the mathematics curriculum: the representation of symmetries and translations in the Cartesian plane.

In the interview (translated from Italian by the authors), Paola explains the path which led her and her colleagues to the design of the STEAM activity described in the template. She reports that the idea for the original nucleus of the activity, emerging at the very beginning of the STEAM-Connect project, involved only two teachers and three disciplines: arts, science and mathematics (these last two taught by Paola herself).

Paola proposes an interesting reflection on the role of mathematics as the main aim of the activity: arts and science were not involved *per se*, but as opportunities to talk about symmetries, starting from concrete examples. Indeed, the activity was carried out during the mathematics class, with the art teacher assuming the role of "special guest".

> Paola: The first collaboration with the art teacher […] entailed starting from the study of symmetries in artworks and in natural elements, to arrive at the discovery of the Fibonacci sequence and the golden rectangle. […] in that case, it was mathematics, let's say, that dominated science and art and it was the art teacher who came in co-presence with me to carry on this activity.

DISCIPLINES	GRADE	TOTAL ACTIVITY TIME	LEARNING OBJECTIVES DURING THE LESSON - DISCIPLINARY COMPETENCIES	LEARNING OBJECTIVES AFTER THE LESSON - NON DISCIPLINARY COMPETENCIES
• Mathematics • Science • Arts • Music • Technology	6th grade	• 12 hours (at school) • 3 hours (at home)	• Building *moduli* with different materials. • Applying the axial symmetry in a drawing. • Representing symmetrical figures in the Cartesian plane. • Identifying symmetries in the piano keyboard. • Recognizing a translation in a polyphonic piece in canon form. • Performing a canon song.	• Recognizing symmetries and translations in art works, music and natural elements (landscapes, flowers, fruits, plants …). • Interpreting images, sounds and movements in a "modular" key • Representing symmetries and translations on the Cartesian plane.

Figure 1. First part of the STEAM activity template.

A similar dynamic is reported by Paola regarding the relationship between mathematics and music, during the first collaboration of the teachers of these disciplines on the topic of symmetries. She explains that the idea of the topic came from a teacher professional development program (SSPM), which she followed at the Mathematics Department of the University of Turin (Pocalana & Robutti, 2022).

> Paola: During the SSPM professional development program, they proposed an activity on the inverse, retrograde canon of music, as an application of symmetries. I was intrigued by this theme, so I asked the music teacher for help and she came to my rescue. We studied a path that started from music and resulted in the representation of symmetries on the Cartesian plane.

On this occasion too, the activity took place entirely during the mathematics classes: it was the mathematics teacher who asked the music teacher to collaborate on a specific topic and the mathematical content of the topic was the main aim of the activity. Figure 2 shows how the relationship between mathematics and the other disciplines could be conceptualized during this preliminary phase of the STEAM-Connect project.

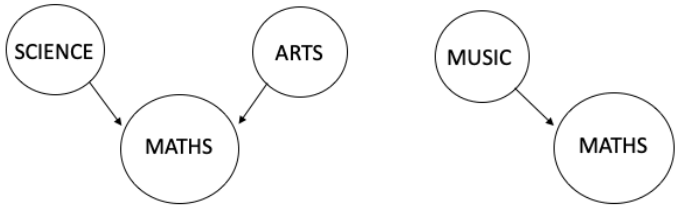

Figure 2. Relationships among disciplines at the beginning of the project.

In the following phases of the project, Paola and her colleagues built on these ideas on the topic of symmetries and translations, asking for the collaboration of the technology teacher to investigate the topic in the case of regular polygons. Paola declares that she was the promoter of the collaboration and that the mathematical content, in this phase, was still the aim of the whole path, even though the activity was designed to be carried out during the curricular classes of all the disciplines.

> Paola: Since the idea started from me and I started to involve the other colleagues, there was the mindset, even when talking about disciplinary contents, of reasoning in terms of mathematical contents.

Paola describes the path of the activity with the metaphoric image of the spiral, because it was designed to converge towards mathematics, in temporal and content terms.

> Paola: We made a sort of spiral, let's say, that is all the disciplines connected, even temporally, one after the other. […] So, the figure that best represents the path, in my opinion, is the spiral, which reaches the top, where mathematics is at the top.

Figure 3a shows how the relationship between mathematics and the other disciplines could be represented at this phase of the STEAM-Connect project. Mathematics is at the end of a path starting with arts, designed to introduce students to the mathematical content of symmetries and translations. Mathematics is, in a sense, the ideal *destination* of the spiral path.

Paola reports that, in the subsequent design cycles of the same activity, the growing connection among teachers enabled by the context fostered a new awareness that all disciplines could be integrated with equal dignity in the path. This awareness gradually changed the relationships between the different disciplines, resulting in other disciplines being no longer considered only at the service of mathematics, but all contributing to providing a wider understanding of a common topic with an interdisciplinary approach (Capone, 2022).

This evolution took place over several months in which the Italian teachers and researchers participating in the STEAM-Connect project met periodically to discuss the design work of STEAM activities and to compare the proposals of the different schools, thus promoting collective reflections.

> Paola: I believe that a path has been outlined in which everyone serves everyone. […] It's not just aimed at introducing mathematics content, I mean, it's not that the work that the technology colleague does, or what the art colleague does has only that purpose. It has a specific aim for each curricular discipline.

Paola also describes the role of mathematics in this advanced phase of the design process as a means of modelling what students discover in the other disciplines, as a lens that enables students to make sense of the complexity of a topic in an interdisciplinary way.

Paola: Mathematics ultimately re-read everything that the students did, in different contexts, with an eye to general modelling.

Figure 3b shows how the interdisciplinary relationship between mathematics and the other disciplines could be represented, in light of Paola's words, after several months of design work in the STEAM-Connect project. At the centre is the common topic of symmetries and translations connecting science, art, technology and music, with mathematics as a lens allowing to focus and model the connections. In this way, the design process as described by Paola reflects mathematics' "particular independence [which puts it] in a special position as regards interdisciplinary relationships" (Piaget, 1972, p. 127).

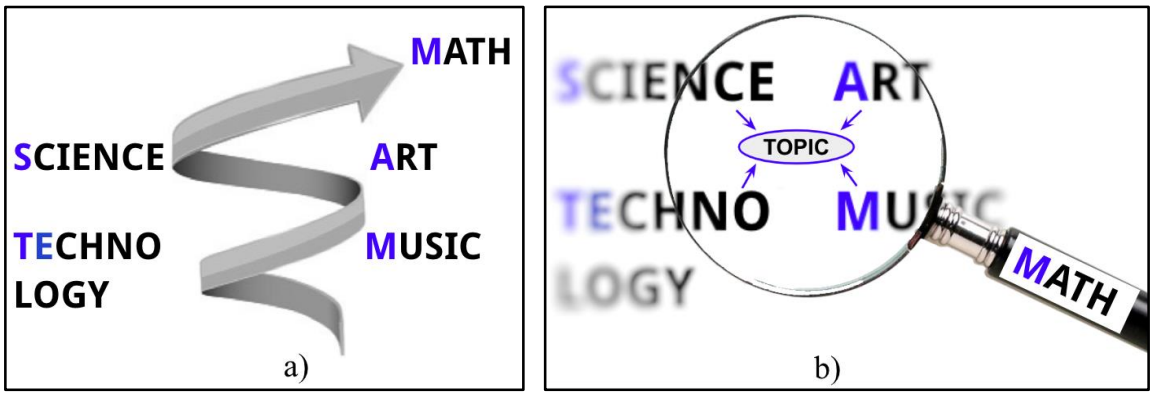

Figure 3. Evolution of the role of mathematics in the STEAM-Connect project.

According to Paola, the collaborative design work carried out in the context of the STEAM-Connect project fostered the awareness of the possibility – not often taken into consideration in Italian schools - to find common topics that could be addressed by different disciplines, creating a sort of "STEAM curriculum".

Paola: I believe that the main outcome of this collaborative design work is the awareness, raised in me and in my colleagues, of being able to find interconnections between the contents of different disciplines.

DISCUSSION

In this study, we conducted a *meta-disciplinary* (Williams & Roth, 2019) investigation, to understand the roles of the different disciplines in the design of a STEAM activity, particularly focusing on the evolution of the role of mathematics. The analysis of the case study revealed that the role of mathematics changed during the different design cycles of the activity. Indeed, during the first experiences of interdisciplinary activities conducted in Paola's school, the role of mathematics was predominant, with the mathematics teacher as the promoter of the collaboration with the art or the music teacher, who were at the service of the mathematical aim of the activity (Figure 2).

In the context of the STEAM-Connect project, as a consequence of the connection between teachers of different schools and researchers, reflecting together on the design of STEAM activities, the relationship between mathematics and the other disciplines started to evolve. The mathematical content of the topic of symmetries and translations

became the ultimate aim of a path, involving the other four disciplines in a "spiral" process leading towards it (Figure 3a). As the project progressed, the teachers collaborated on an increasingly equal basis to the design of an interdisciplinary STEAM activity with shared objectives, meaningful for all the involved disciplines (Figure 3b). The topic of symmetries and translations was perceived as a common object to all the disciplines, even though it was proposed by the mathematics teacher.

The different levels of connections favored by the STEAM-Connect project increased teachers' awareness of the possibility of collaboratively designing interdisciplinary activities on a shared topic. This awareness gradually moves them from a teaching paradigm focused on the knowledge products of the different disciplines to a teaching paradigm aimed at eliciting the processes that gave rise to the knowledge products and their mutual relations. A new awareness has also been reached of the modeling role of mathematics, which enables students to read natural phenomena or artistic expressions through a common lens.

Reflecting on how to connect different disciplines, each with its specific epistemology, in the design of an interdisciplinary "STEAM curriculum" could be both a developmental aim for the next phases of the project and a venue for future research.

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