The role of teachers' experiences and beliefs in the conceptualization of mathematics within the design of STEAM activities

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In this paper, we study the role that secondary school mathematics teachers attribute to mathematics in the design of STEAM activities for their students. We focus on the description of the design process provided by four mathematics teachers during semi-structured interviews. We triangulate data by investigating teachers' beliefs about mathematics by means of a written questionnaire. We found that previous experiences in professional development programs enable all four mathematics teachers to play a leading role in the design of STEAM activities. Consequently, in all four cases, mathematics has a focal role with respect to the other subjects. A crucial difference among the teachers is that only two of them have some experience in designing interdisciplinary activities and take into account the epistemological peculiarity of mathematics as a lens to model reality and understand the world. This difference influences their conceptualization of mathematics in the design of STEAM activities.

Keywords: STEAM education, STEAM activities, design, modelling, teacher beliefs.

Introduction and theoretical background

In this paper, we aim to investigate the role attributed to mathematics by secondary school mathematics teachers involved in the design of STEAM activities for their students. Specifically, we would like to shed light on how teachers' previous professional experiences and beliefs about mathematics influence the role that they attribute to mathematics and shape the design process.

Many teachers consider STEAM activities as involving all the subjects of the acronym (Science, Technology, Engineering, Arts, and Mathematics), but often they have no clear idea of how to implement their integration (Breiner et al., 2012; Wang et al., 2020). Indeed, although STEAM integration encourages interdisciplinary collaboration, generally teachers are not trained to design and implement interdisciplinary activities (Maass et al., 2019).

The interdisciplinary approach is the heart of STEAM education, which has to take into account the epistemologies of different subjects such as arts, sciences, and mathematics, by engaging students in analytical, intuitive, logical, and aesthetic ways of thinking (Henriksen et al., 2019). Interdisciplinarity in STEAM teaching involves integrating subject matters in "ways that engage people in creativity, problem-solving, and project- or problem-based learning" (Henriksen et al., 2019, p. 59). In this context, showing that mathematics is a powerful means of understanding the world is a fundamental aim of STEM and STEAM education (Maass et al., 2019). Indeed, capabilities such as critical thinking, problem-solving, and analytical skills, which are also twenty-first-century skills (e.g., European Commission, 2018), can be enhanced through the use of mathematics as a means to understand the world (Maass et al., 2019). Borrowing the words of Schoenfeld (2017) about teaching for robust understanding, "We have been feeding children mathematical fish for hundreds if not thousands of years. It is time to teach them how to fish" (p. 104).

Mathematics can be considered on three levels: inside the school environment mathematics is a subject *per se*, with its own epistemology enabling understanding of concepts internal to mathematics

itself, and it is a subject deeply connected to other subjects, a common language that enables to see patterns, to model and to predict different phenomena; outside the school environment, mathematics is a subject in relation to the real world, a means to build citizenship skills and understand the world (Figure 1).

Figure 1: Different levels of mathematics understanding

In research, it is recognized that the way in which teachers conceptualize mathematics is strictly connected to their beliefs about the nature of mathematics (Cross, 2009), which can "range from viewing mathematics as a static, procedure-driven body of facts and formulas, to a dynamic domain of knowledge based on sense-making and pattern-seeking" (Cross, 2009, p. 328). These beliefs influence how teachers conceptualize their role, the role of mathematics, their design of classroom activities and their teaching practice (Cross, 2009, Wang et al., 2020).

As beliefs influence teachers' classroom practice, they are in turn influenced by teachers' previous experiences both as students at school and in professional development (PD) programs (Liljedahl, 2005; Rice & Kitchel, 2017). Furthermore, other elements impact on teachers' beliefs, such as their knowledge and skills (Buehl & Beck, 2014), curriculum and standards, school and classroom environments; and education-related policies (Buehl & Beck, 2014). For these reasons, we can say that teachers' beliefs and practices are very much influenced by the context in which teachers work, their professional experiences, and their background (Wang et al., 2020).

When mathematics teachers are involved in interdisciplinary teaching (like in STEM or STEAM teaching) they have to find their role and to conceptualize mathematics, in order to be able to connect with colleagues teaching other subjects with their languages and principles. As underlined in the work by Den Braber et al. (2022), presented at the CERME12 conference, giving voice to mathematics teachers involved in interdisciplinary teaching could enable us to learn from their experience in shaping their role and understand the connections with their background, skills, and beliefs about mathematics.

If this is true when teachers are engaged in teaching STEAM activities designed by someone else, it is even more true when they are directly involved in designing their own STEAM activities and, therefore, they have to understand how to position mathematics in the design process. Thus, we set off for our study guided by the following research questions:

RQ1) What is the role attributed to mathematics by Italian secondary school mathematics teachers designing STEAM activities?

RQ2) How do teachers' previous experiences and beliefs influence this role attribution?

Methodology

Institutional and experimental context

Our study is conducted in the context of the Erasmus+ Project STEAM-Connect (Co-creating Transdisciplinary STEM-to-STEAM Pedagogical Innovations through Connecting International Learning Communities), in which researchers from different countries (Austria, Finland, Italy, Luxembourg, and Slovakia) and secondary school teachers of different subjects (arts, mathematics, music, science, technology, etc.) work collaboratively to design STEAM activities for all school grades. At the beginning of the project, it was agreed that not only art in a strict sense should be accepted within the letter A of the STEAM acronym, but also music and humanities in general, such as philosophy.

The STEAM-Connect project started in November 2021 with the researchers co-creating a common template to be used by teachers who design the STEAM activities to organize their productions according to a shared structure. The purpose of the common template is twofold: (1) to help teachers with the integration of the disciplines by providing organized sections to indicate the subjects involved in the STEAM activity, the total amount of time needed to implement the whole activity, the subject-specific learning objectives of the activity, and the transversal long-term learning objectives; (2) to support the exchange, sharing, and dissemination of the STEAM activities in the following part of the project, which will run until the end of 2024. In this part, the teachers involved in the project work on the design of STEAM activities in three phases, involving three levels of growing connection.

In the first phase (connection at the school level) teachers from each school collaboratively design STEAM activities, in the second phase (connection at the national level) the STEAM activities are shared with other schools of the same country, and in the third and final phase (connection at the international level) the STEAM activities are shared with other schools in different countries. In this study, we focus on the first phase.

As a peculiarity of the Italian institutional context, we acknowledge that upper-secondary school mathematics teachers often also teach physics, and lower-secondary school mathematics teachers also teach science. Nevertheless, they usually do not teach these subjects in an integrated way engaging students in interdisciplinary activities, also because the institutional references (national curricula) do not support them in this integration. Consequently, teachers, in Italy (Branchetti et al., 2019) as in other countries (Den Braber, 2022), generally have no clear understanding of how to conduct interdisciplinary teaching, involving subjects with different epistemologies like mathematics and experimental sciences, let alone STEAM activities.

Data collection and data analysis

In this study, we observed four mathematics teachers, three at upper-secondary level (Cristina, Pietro, Silvana) and one at lower-secondary level (Paola), one for each Italian school participating in the STEAM-Connect project. All of them have a long teaching experience and have followed PD

programs provided by the Mathematics Department of the University of Turin. In particular, they have been following the SSPM PD programs (Scuole Secondarie Potenziate in Matematica, i.e. Secondary Schools Enhanced in Mathematics, see also Pocalana et al., 2023) for several years, focused on laboratory teaching (Arzarello & Robutti, 2010) and inquiry approach (Swidan et al., 2023). Two of the teachers (Paola and Silvana) already experimented with designing interdisciplinary activities at school level, while the other two (Cristina and Pietro) are newbies in the field.

Coherently with our aim to investigate how mathematics teachers perceive and position mathematics in their design of STEAM activities in relation to their professional experiences and beliefs about mathematics, we articulated our data collection in two steps. In the first step, we collected data on the design of their own STEAM activities through oral semi-structured interviews conducted online by the first and the second author during the design process (January 2023). Interview questions focused on the development of the design process, the role of mathematics, and the role of the mathematics teacher. In the second step, we collected data on teachers' beliefs about mathematics through a written online questionnaire with four open questions, requesting teachers to complete the following sentences in less than 200 words: "Mathematics is …"; "Being competent in mathematics means…; "Teaching mathematics means …"; "Learning mathematics means …"

We analysed data through qualitative analysis with an open coding approach, triangulating data coming from the different sources (interviews and questionnaires) to increase the reliability of the results. To address our research questions, codes and categories focused on themes related to the role of mathematics and the role of mathematics teachers in the design of STEAM activities, and themes related to the nature of mathematics.

Results

Description of the STEAM activities

From the interviews, we derive a description of the STEAM activities designed in the four Italian schools participating in the STEAM-Connect project. In Table 1, we provide a schematic summary of these activities including the school level, the subjects involved, and the general topic.

Table 1: STEAM activities designed in the four Italian schools participating in the project

School level	Mathematics teacher	Disciplines	Topic
Lower-secondary	Paola	Mathematics, Arts, Music, Technology, Science	Symmetries and translations
Upper-secondary	Silvana	Mathematics, Arts, Philosophy/History, Music	Everything is number: Pythagoras and the irrational numbers
Upper-secondary	Pietro	Mathematics, Arts, Science, History, Computer science.	Pascal (Tartaglia) triangle and golden section
Upper-secondary	Caterina	Mathematics, Arts, Philosophy, Science.	Polygons, polyhedra, and spiral of Theodorus.

The role of teachers' previous experience and background

In the interviews, when asked about their previous experiences inspiring their design of a STEAM activity, all teachers mention the SSPM PD programs with the name *Liceo potenziato in matematic*a, or simply *potenziato.*

Caterina: I was thinking, for example, about the activity of the *potenziato* [SSPM] because that's where we mostly design activities. The first activity that came to my mind is the one that was proposed by the University, that of the sea level, connecting mathematics and physics.

Silvana: We started from what we had already done in the previous experiences within the *Liceo potenziato in matematica* [SSPM]. [...] Two years ago, I started to work with my colleague of history and philosophy on the activities proposed in the *Liceo potenziato* and now we are going further.

Pietro: We, mathematics teachers, are more used to designing activities with different tools and materials [other than textbooks]. I think that, for example, the history teacher almost only uses a teacher-centred formal lecture approach and little else.

From these excerpts, we observe that the peculiar expertise of the mathematics teachers, who are used to design student-centred and inquiry mathematics activities (Pocalana et al., 2023) thanks to the SSPM PD programs, position them in a strategic role with respect to their non-mathematics colleagues, who are not used to design activities and usually rely on teacher-centred formal lecture. We interpret this as a possible reason to explain why mathematics is so pervasive in the STEAM activities topics, as seen in Table 1.

The role of mathematics

Using data from the interviews and the online questionnaires, we now present some details on the role that the teachers designing STEAM activities attribute to mathematics. In the interviews, Caterina and Pietro, asked to describe the role of mathematics, confirm its central position and its focal role among the other subjects during the whole activity. Both teachers spontaneously paired this description of the focal role of mathematics with a description of their own focal role as teachers. They delineate the mathematics teacher as the one choosing all the connections between mathematics and the other subjects and coordinating other colleagues (Caterina) or as the one proposing the connections, eliciting the contribution of other colleagues and encouraging the communication among subjects (Pietro).

Caterina: Mathematics is the *center* and I am the *center* of my colleagues.

Pietro: Mathematics should be the *ending* of the path, temporally speaking, but it is also the *goal* of the path [...].

Pietro: The mathematics teacher *coordinates*, in the sense that I have had the ideas and I distributed the works. But I asked the opinion of my colleagues.

Coherently, in the questionnaire, Caterina and Pietro express beliefs on the cultural role of mathematics, conceived as a subject *per se*. Indeed, Pietro writes that "[Mathematics is] reasoning, discovery and beauty", and Cristina writes that "[Mathematics is] fun, challenge, passion, creativity, satisfaction and beauty".

The other two teachers, Paola and Silvana, when asked to describe the role of mathematics, both point out its role as a modelling lens to understand phenomena.

Paola: Mathematics ultimately reinterprets everything done by the students in different contexts, in a general *modeling* perspective.

Silvana: We are trying to work on a path that we have called "*Everything is number*".

We read Silvana's words as revealing a view of mathematics as a common language enabling us to see patterns and to model reality.

Paola's answers to the questionnaire confirm her belief about the modelling role of mathematics. For example, she writes that "[Mathematics is] a key to understanding reality" and that "[Being competent in mathematics means] knowing how to use the tools of mathematics to model reality". In the questionnaire, Silvana expresses a similar view of mathematics, writing that "[Being competent in mathematics means] being able to model [...]" and that "[Teaching mathematics means] helping my students understand the world through the eyes of numbers [...]".

Contrasting and comparing our data across teachers' answers, we realise that all four teachers position mathematics in a focal role in the design of STEAM activities but this role is conceptualised in different ways, that we represent in Figure 2.

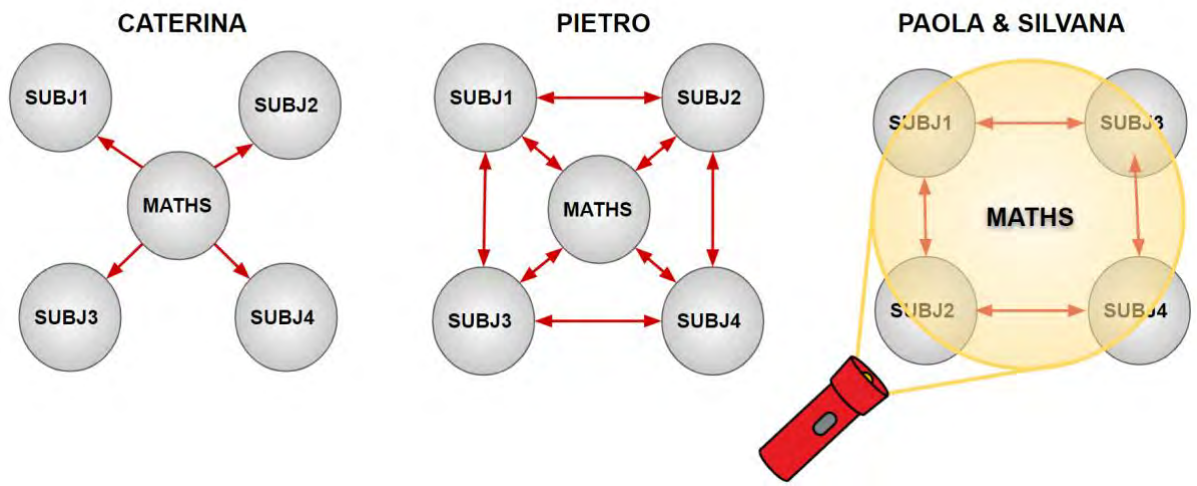

Figure 2: Different roles of mathematics in the design of STEAM activities

Reading Figure 2 from left to right, we observe that mathematics passes from being the operational centre of the design process (Caterina, left), to being a catalyst for a synergic connection among subjects (Pietro, centre) to being a cultural tool to understand the world (Paola & Silvana, right), a torch that allows students to see patterns and to model phenomena. If we analyse these differences in light of the different experience of the four teachers with interdisciplinary design, we see that Paola and Silvana, who have some experience in this field, consider mathematics in relation to other subjects taking into account its epistemological peculiarity, while Caterina and Pietro consider mathematics *per se*, simply as the linking element in the interdisciplinary work.

Conclusion and discussion

The results of this study reveal that all four mathematics teachers attribute a focal role to mathematics with respect to the other subjects when designing STEAM activities (RQ1), thanks to their design experience gained in SSPM PD programs. If this aspect is common to all the teachers, the results reveal also a crucial difference. Only two teachers, Paola and Silvana, attribute to mathematics an epistemological peculiarity with respect to the other subjects, viewing mathematics as a lens enabling one to model and understand all the topics presented in the STEAM activities. Among the other two teachers who do not express this view, another difference can be noticed: Caterina plays a more directive role with respect to Pietro, who encourages the exchange of ideas among all the colleagues. We can observe that the less experienced the mathematics teachers are in designing interdisciplinary activities, the more they are anchored to their subject considered *per se* (RQ2).

The research results of this study contribute to deepening our insight into how the mathematics teachers participating in the STEAM-Connect project conceptualize the role of mathematics in the design of STEAM activities, in the current phase of connection at school level. Further research could be conducted to study the joint work of researchers and teachers in the subsequent phases of the project, aimed at converging towards a shared conceptualisation of the role of mathematics, thanks to a connected dialogue. Indeed, we embrace the idea that the main goal of interdisciplinary STEAM teaching is that of integrating subject matters, engaging students in creative activities and problem-solving (Henriksen et al., 2019). For these reasons, the next steps of our project will be aimed at promoting the design of STEAM activities that start from concrete, non-curricular problems, taken from the daily reality of students, which can be analyzed from the different points of view of the involved disciplines, each characterized by their peculiar epistemologies.

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