STUDENTS' CONCEPTIONS ABOUT MATHEMATICS FOR CLIMATE CHANGE AND RELATED ISSUES

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In recent PME and ICMI conferences, a need for curriculum innovation that takes into account the role of mathematics in understanding and contrasting climate change and related issues has been stressed by prominent scholars, taking a rather cognitive stand. In this paper, we focus on the affective side of the phenomenon, arguing that the students' conceptions both about mathematics and about climate change and related issues need to be taken into consideration in order to make such an innovation effective. Hence, we report and analyse the narratives that a small sample of students enrolled in an Environmental Sciences program produced during the activity of writing a letter to a fictitious class of students living in the future describing how mathematics has helped humans to survive in the next 200 years.

INTRODUCTION AND THEORETICAL BACKGROUND

Mathematics, according to Coles (2023), plays a central role in dealing with, yet responding to, issues like climate change, population growth, pollution, resource scarcity and wastefulness, but the mathematics that is taught at school is scarcely (if not at all) connected to these ideas (Coles, 2023). Coles (2023) shows examples of curriculum innovation for mathematics more connected to these socio-ecological issues that emerge in the new climatic regime. He proposes changes of the content that students should learn in mathematics classes. In this paper, we propose to add reflections on the role of students' conceptions, both about mathematics and about socio-ecological issues, being the latter a relevant yet unexplored element that influences the learning of mathematics (Coles, 2023). According to many studies (e.g., Sumpter, 2013), the ways students engage with mathematics depend on their different affective disposition. A variety of researches focused on how mathematics is perceived and dealt with, such as the different motivation students' express (Nyman & Sumpter, 2019), or how different expectations function as a mediator for various choices students make when solving mathematical tasks (Sumpter, 2013). Among all the mentioned affective dimensions, beliefs received special attention in research. According to Furinghetti and Pehkonen (2002), beliefs are the conclusions that an individual draws from their perceptions and experiences in the world around them. Beliefs can be understood as subjective knowledge: they are propositions about a certain topic that are regarded as true (Philipp, 2007). Being continuously subject to new experiences, beliefs can change and new beliefs can be adopted (Furinghetti & Pehkonen, 2002). When a new belief emerges, it never comes in isolation from other beliefs, but becomes part of, what has been called, an individual's belief system. According to Green (1971), in fact, beliefs tend to form clusters, as they "come always in sets or groups, never in

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complete independence of one another" (Green, 1971, p. 41). These clusters form a system, which is organised according to the quasi-logical relations between the beliefs and the psychological strengths with which each belief is held (Green, 1971). Belief clusters are, thus, almost coherent families of beliefs across multiple contexts: for example, beliefs about the nature of mathematics and about its learning tend to cluster in a quite coherent way, for a student. This has probably led Furinghetti and Pehkonen (2002) to conclude that "an individual's conception of mathematics [is] a set of certain beliefs" (p. 41), namely to understand conceptions as clusters of beliefs. Liljedahl (2018) further prompts the research field to consider beliefs not as operating as singular entities, but in synergy with emotions and attitudes, to form what he called an affective system. Several researchers stress how motivation, emotions, and beliefs are intertwined, with each other (e.g., Liljedahl, 2018) or internally such as different types of motivation being combined in one statement (Nyman & Sumpter, 2019), or such as attitudes being conceived as an amalgam of emotional disposition, perceived competence and view of mathematics (Di Martino & Zan, 2011). For this reason, in this paper we decided to use the construct "conceptions", which is meant as an umbrella concept, namely: "a general notion or mental structure encompassing beliefs, meanings, concepts, propositions, rules, mental images, and preferences" (Philipp, 2007, p.259). Hence, conceptions may have both affective and cognitive dimensions and serve the purpose of capturing students' ideas and dispositions (Philipp, 2007).

The aim of the paper is to showcase a pilot, small-scale study on students' conceptions about mathematics and about climate change and related issues. To that end, an activity consisting of writing a letter to fictitious future students living 200 years ahead to show how sciences and mathematics contribute to the survival of life has been carried out. This kind of activity is called speculative storytelling (Helliwell & Ng, 2022): the arts and humanities can provide opportunities to engage with socio-ecological issues and to alter attitudes and behaviours in ways that formal scientific approaches on their own do not. It has been argued (Helliwell & Ng, 2022) that teaching and learning approaches involving a variety of art forms and aesthetic elements have qualities that could develop education, especially with respect to climate change. This kind of issues is commonly perceived as distant and abstract, but arts and humanities can contribute to make it closer and concrete for students (Helliwell & Ng, 2022). Issues like climate change are also overwhelming and difficult to grasp, but arts and humanities can help express negative emotions (Helliwell & Ng, 2022). Helliwell and Ng (2022) further maintain that to work in this way entails drawing on multiple forms of knowing (i.e. cognitive, sensible, somatic, affective). Specific to speculative storytelling, Helliwell and Ng (2022) utilised it as a curriculum innovation. The researchers used speculative storytelling primarily as a way of engaging the participants in sharing their ideas and collaborating around the topic of sustainable futures in the mathematics classroom. The researchers also recognised a potential for speculative fiction as a pedagogical tool for prompting students' imagination, deemed as a way to conceptualise alternatives to what is taking place and, thus to realise that certain facts are contingencies and not necessities. According to Helliwell and Ng (2022), it is this kind of imagination that

enables a suspending and letting go of taken-for-granted ways of being to contemplate more just and equitable futures.

In our research, we apply these ideas to engage students in speculative storytelling about how mathematics can help surviving for the next 200 years. This activity has a double goal: it allows conceptions about mathematics, brought from school, to emerge, and it prompts students to imagine other roles of the discipline beyond the boundaries of what was taught to them during the school years. Thus, the research question we aim at answering is: can the conceptions that emerge in an activity of this sort contribute to understand how students approach not only mathematics, but also the mathematical activities centred on socio-ecological issues?

METHODS

The participants to the study are 32 students enrolled in the first year of an undergraduate program in Environmental Sciences, in an Italian University. They are 10 females and 22 males aged 20 years, with an exception of two students who are 28 years old. At the time of data collection, they were attending the first lecture of the mathematics course, led by the author. The sample represents 70% of all the students enrolled (other 12 students usually did not show up during the classes).

With respect to data collection, it is well acknowledged that much of the studies on affective aspects have been conducted through narratives such as essays, diaries, questionnaires with open questions and interviews (e.g., Kaasila, 2007; Di Martino & Zan, 2011). In line with the method of narrative data collection (Kaasila, 2007), the students of our sample were asked to answer an open prompt, that is:

> We got a letter from the future: the people who live on Earth in 200 years wrote to us. They say that on Earth there is life, it is possible to breathe fresh air, to drink water and there are the conditions for thinking about the future. They ask us, however, to tell them how we made it possible and which was the role played by mathematics (and sciences). Answer to them, individually.

The students were given 20 minutes to reply, and data were collected anonymously. Each student had been assigned a label, like S1 for student 1. The goal of the narrative approach is to get the respondents to tell stories about things that are important to them, feeling free to express their conceptions, reporting the aspects that they consider central in their own experience (Kaasila, 2007; Di Martino & Zan, 2011). Moreover, with open prompts, respondents are not forced to align their opinion on a ready-made list chosen by the researcher (Di Martino & Zan, 2011).

The collected narratives were analysed according to holistic and categorical approaches (Lieblich, Tuval-Mashiach & Zilber, 1998). In a holistic approach, the narrative is analysed as a whole, and the focus is on the overarching themes that emerge from whole responses, instead of focusing on specific terms or concepts that are expressed in a specific text. For example, the narratives with respect to one's relationship with mathematics can refer to themes which span from the positive

feelings during primary school days to the anxiety before the exams. These themes, emerged from the data and not created in advance by the researcher, are considered for holistic analysis and grouping. In a categorical approach, in each narrative, sections or even single words are taken into account (Lieblich *et al.*, 1998) and then classified by the researcher through semantically identifying expressions that refer to a same category (also categories emerge from the data). Elaborating on the previous example, some students may mention the pleasure of working with geometrical figures, thus their narratives (sections or words) are grouped by the researcher in a specific category (e.g., "GF"), others may recall counting games, contributing to a different category (e.g.,"CG"), and so on. In this way, the overarching theme of positive feelings with respect to mathematics at primary level is specified in categories "GF", "CG" and so on. A narrative from a single student can contain expressions that belong to different themes and categories, and some categories might not belong to a unique theme. Moreover, some categories, which emerge from sections and words, might not be associated to any theme. The combination of a holistic and a categorical approach, allows for a deeper and differentiated understanding of the narratives (Kaasila, 2007) firstly focusing on the general, overarching themes that emerge across the narratives, then going into details focusing on the categories. Accordingly, it is appropriate to apply the classification made by Lieblich *et al.* (1998) as "an analytical bridge: the ultimate purpose can be to integrate the approaches into a whole" (Kaasila, 2007, p.5). This method catches and operationalizes, in our view, the idea developed in our theoretical framework that conceptions form a system (Philipp, 2007; Liljedahl, 2018).

DATA ANALYSIS

The holistic approach allows to identify two general themes that emerge from the narratives and that are recurrent across several narratives: *progress* and *role(s) of mathematics*. The first theme emerges in 17 narratives: the students use expressions like: progress, development, increase. They mention technological progress, progress of knowledge and culture, scientific progress, as means that would make life possible on Earth in 200 years. In students' narratives, there is a trust in the progress as a way to mitigate and contrast the existing trend. The second holistic theme, which can be found in 15 narratives, concerns the *roles of mathematics*. In this case, mathematics is not only mentioned, nut the possibilities offered by the discipline to save the world are specified. The roles of mathematics that mostly emerge from the narratives are: computation; data analysis to get the sense of the extent of pollution, hanger, resource use, energy, wastefulness; problem solving; estimation of risk; modeling. Taking on a systematic stance on students' conceptions, the holistic analysis allows us to infer that these two main themes span across students' narratives.

Categories

Afterwards, with the categorical approach we identify words in the narratives possibly related to the two holistic themes. With respect to the *progress* theme, we labelled the words and statements used by the participants in 4 categories, while to the holistic

theme of *roles of mathematics* other 5 categories have been attached. Furthermore, we identify other 3 categories that do not relate to any holistic theme. We also note that, with respect to gender, we observed no particular difference in the ways females and males express their ideas, nor a predominance of certain themes or categories in either gender group.

The holistic theme "*progress"* is associate to 4 categories: technological progress (T, 9 students), mathematics as key for progress (K, 8 students), discovery (D, 6 students) and acquisition of new knowledge (A, 4 students). Examples are:

> New technologies have been implemented and they have improved our lifestyle, reducing the risk of floods and earthquakes and limiting their gravity and flow (S12, category T).
>
> As regards the aspect of planetary conservation, through the discovery of new chemical elements and the improvement of existing ones, new substances have been created capable of neutralising all the polluting effects of materials, such as plastic, to encourage growth and ecosystem development. In the context of other disciplines, it has been possible to solve world hunger by creating fast and efficient means of transport that reach all points of the Earth, powered by solar energy. Through the in-depth study of space launches on the Moon, it was possible to reach Mars and make the most of its resources (S6, T).
>
> Everything is related to knowledge that has increased constantly. The fact that in 200 years life is possible on Earth prompts me to think that this trend did not decrease but it has increased (S1, A).
>
> A slow improvement to the social, economical and political situation has taken place thanks to an incessant development of science and mathematics (S5, A).
>
> Mathematics and science have been the keys of the progress since ancient times, and continue to be (S2, K).
>
> Mathematics and science are essential to a progress that is aimed at safeguarding the well-being of life and that of the planet (S23, K).
>
> Also in the past, Pitagora, Euclid, Gauss, Newton, Einstein, Galilei are among the mathematicians and scientists who changed the world (S2, D).
>
> Mathematics has developed and has been able to find answers as long as the questions become more complicated (S26, D).

The first two excerpts focus on technological progress in general (S12) and on specific technological innovations in particular (S6) and have been identified within the category T. The third and the fourth excerpts focus on the progress of knowledge. Student S23's statement has been related to category K, while the last two statements are examples for category D, which includes also change. One can notice that the word "progress" is either explicitly mentioned in these excerpts, or it is evoked by expressions that relate to it, while mathematics is not always mentioned explicitly. In the other 19 statements (of the 27 in total) that are not reported here, only 6 explicitly mention mathematics, and this is interpreted as if the students are not always aware of the importance of the discipline for technological progress. We stress that those who mention mathematics under this theme, they mention it in a general way, detached from

possible practical implications and uses of the discipline towards progress and innovation (see in the last four examples reported): a specific role for mathematics is not described, nor how it contributed concretely to progress).

Within holistic theme of the *roles of mathematics* we found five categories: solving problems (S, 8 students), analysing data (DA, 8 students), estimating probability of impact (P, 5 students), explaining (E, 2 students), modelling (M, 3 students). Examples are:

> Mathematics has provided us with solutions to many problems (S28, S).
>
> I give you an example: we know that global warming is one of the most important problems nowadays and thanks to mathematics we have been able to locate the problem, search for a solution, apply the solution and monitor if this solution works (S4, S).
>
> Thanks to countless surveys, studies and research done on man and regarding his habits and vices, and on nature, we have managed, albeit slowly, to change the fate of our planet (S5, DA).
>
> Researchers and data analysts collect data about all the issues (S18, DA).
>
> Without data analysis, without a tool to control the data, we would not be aware of the gravity of certain situations and, thus, we would not do enough to improve (S14, DA).
>
> Mathematics and science have contributed to give an explanation to all phenomena that were inexplicable (S2, E).
>
> Through precise and complex mathematical computations we will be able to optimise the resources and to use them in various contexts (S23, M).
>
> Mathematics has allowed to create models that favour the social system, which was precarious in the beginning (S6, M).

In these example, mathematics's roles are detailed, as well as in the other narratives not reported. Mathematics is associated mostly to computations and handling of data, and more rarely to modeling and predicting.

Other three categories not related to a specific holistic theme emerged: collaboration among disciplines (C, 8 students); the relationship between theory and practice (TP, 5 students); the role of education (ED, 4 students).

> The interaction among disciplines has led to enormous steps forward (S1, C).
>
> Mathematics allows for the solution of real problems through a theoretical approach, science is a discipline that that has numerous applications and concerns the pragmatic side of phenomena, giving explanations through observations and experiments (S7, TP).
>
> Thanks to people like us, we will be able to educate people to a more sustainable way of living (S18, ED).

One can notice that also in these examples, mathematics is mentioned in limited cases, but when it emerges (e.g., in S7), it is compared to sciences and a specific role is recognised to the discipline. Finally, one student admits that he never thought about

the role of mathematics in tackling these issues and has no idea (S22). No category has been assigned to it.

Figure 1 summaries our holistic-categorical approach analysis: the two holistic themes (green circles) are *progress* and *roles of mathematics* and are linked with categories (orange circle), while the others are disconnected. For our purpose, the two identified holistic themes can be seen as a first classification of conceptions about the topic under analysis, while the categories represent a specification on those conceptions. Of course, these themes are not surprising, because it is well acknowledged the importance of progress to mitigate the effects of climate change and to adapt to the new regime, and because the task explicitly asked about mathematics. In a sense, it is not surprising for us that students' conceptions can be grouped under these themes, as conceptions encompass beliefs, meanings, concepts, propositions, rules, mental images, and preferences (Philipp, 2007) about climate change and related issues in our study. Moreover, the four conceptions linked to progress, for example, allow us to better specify the conceptions students have on progress, which focus on technology, development of knowledge, discovery and on mathematics as a basis for it. With respect to mathematics, we can conclude that students' conceptions of the discipline as a tool to solve problems and deal with data are prevalent.

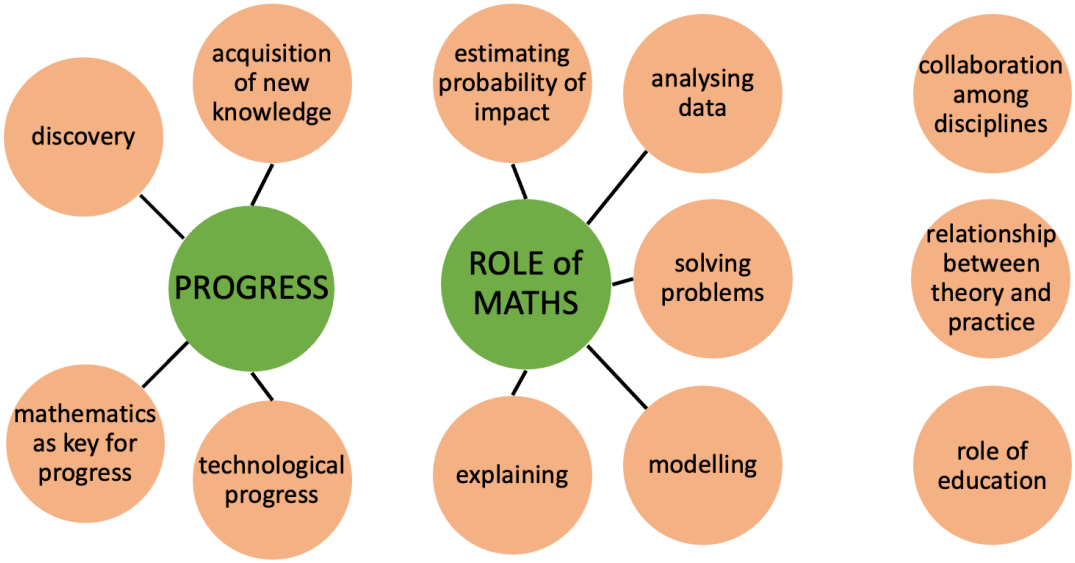

Figure 1: The holistic themes (green) and the categories (orange) that emerge from the data analysis. A line for categories that can be connected to a theme is drawn.

DISCUSSION AND CONCLUSION

We explored conceptions about role of mathematics in contributing to contrast and mitigate issues like climate change and to make life possible in the next 200 years. We identified two holistic themes and found 12 categories for conceptions. We noticed that the students do not always mention mathematics explicitly when talking about progress and the role of education. In our interpretation, and according to the theoretical framework, this could be due to the fact that mathematics at school is taught without

application to the world (Coles, 2023): this means that even in activities that leave the imagination free and that are specifically designed to prompt such an imagination (Helliwell & Ng, 2022), students seem unable to see a role for mathematics. In other words, in this research possible futures are imagined by the students (Helliwell & Ng, 2022), leaving the mathematics relatively aside, or with a very vague role. In the conceptions associated with the roles that mathematics takes on, the discipline is central but emerges often as calculations on data, rarely as modeling or a tool for making predictions. This reflects, in our interpretation, the kind of mathematics that students learn and do at school, namely rote exercises, computation and algorithms. As a conclusion, we argue that in innovating mathematical curriculum, it is necessary to monitor also if and how the students' conceptions change to make it possible for them to consider new ways of seeing mathematics, especially as a discipline that contributes concretely to progress.

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