Mathematics on the river, mathematics of the river: unveiling the power of mathematical conceptions

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Abstract: The research presented in this paper explores mathematical conceptions on one side, and on the other side number sense and forms of knowledge (such as knowledge about rivers) that people mobilize during citizen science activities that foster the 6th and 15th United Nations' Sustainable Development Goals, namely the ones addressing water quality and quantity, and biodiversity in water. A sample of 28 students from an Environmental Science course participated in a pilot phase of the project and the data they voluntarily provide represents the data source. A multiple-choice questionnaire, paired with open prompts, has been administered and students' conceptions of both rivers and numerical facts about rivers emerge: in fact, rivers represent more a risk for floods and source of water for human activities, rather than a place for biodiversity to flourish. Numerical facts about rivers in Europe are also little known. We conclude that conceptions shape the way people perceive rivers, also in its numerical facets.

Keywords: mathematical conceptions, number sense, sustainable development education, the river context

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1 Introduction and background

This research addresses the sixth and fifteenth United Nations' Sustainable Development Goals (SDG6; SDG15), which acknowledges that human activities are compromising water resources and their biodiversity through overexploitation and pollution, and which clarifies how water quality, quantity and access are crucial to human well-being (Taylor et al., 2022). Mathematics, according to Coles (2023), plays a central role in dealing with, yet responding to, such issues, but the mathematics that is taught at school is scarcely (if not at all) connected to these ideas (Coles, 2023) and Andrà and Brunetto (2024) provide evidence that students find it difficult to imagine a role for mathematics in the real word, since at school mostly rote learning is promoted (Coles, 2023). In this paper, we propose to add reflections on the role of students' conceptions, both about mathematics and about ecological issues in the context of rivers, being the latter a relevant yet unexplored element that influences the learning of mathematics (Coles, 2023). The scope of the study is to see how conceptions emerge when students are faced with numerical facts about rivers.

According to Leighton and Bisanz (2003), conceptions are referred to as informal theories, and they incorporate beliefs individuals hold about the world. 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 complete independence of one another" (Green, 1971, p. 41). These clusters form a system, which is organized 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 (but not necessarily) 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. 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). In the context of our research, indeed, the need for an umbrella concept emerges as a necessity, being mathematics-related beliefs intertwined with many other affective elements that concern rivers. This is also why we argue that the construct of number sense captures some interesting features of mathematical conceptions that are central for the context of our research. Numeracy, in fact, has been defined by Douglas et al. (2021) as the understanding of quantities including how they relate to each other and map onto number words and numerals. Beswick (2008) further notes that definitions of number sense typically emphasize the use of mathematics in everyday life and highlight the importance of affect, as being numerate implies having the knowledge and disposition to think and act mathematically and the confidence and intuition to apply specific mathematical principles to problems emerging in the real life.

Numeracy, according to Liljedahl (2015), can be seen as an intertwining of mathematical knowledge, tools, and dispositions, as "to be numerate means to be willing and able to use this knowledge, tools, and dispositions across a wide variety of contextual (even real) situations" (p.625). Numeracy is, thus, conceived as an amalgam of knowledge, conceptions and practices.

Back to the context of environmental education, Taylor et al. (2022) stress out the need to involve all society in turning the situation around. In this direction, recently it has been found that citizen science and co-engaged action learning (O'Donoghueet al., 2018) are unfolding as inclusive, enabling and effective social change processes. In resonance with findings in the field of affect-related research in mathematics education (Hannula, 2012), but specific to SDG6 and SDG15, Taylor et al.'s (2022) approach allows to deepen the understanding of water and biodiversity conservation issues in a practical and applied manner and enables actions for more sustainable practices: in other words, it links understanding, conceptions and practice. Biodiversity in river water implies: (i) knowledge, including the one on proportions in rivers, (ii) conceptions, namely dispositions, motivation, willingness to know and preserve such ratios of different living beings, (iii) action to enable, concretely, such a preservation, or mitigation of negative effects of human lifestyle. We focus in particular on conceptions, meant as families of beliefs. In the context of mathematics teacher education, we recall that Guskey (1986) showed that beliefs could change. In Guskey's elaboration, specifically and interestingly, beliefs can change following changes to practice, when a change in practice shows evidence of students learning. Liljedahl (2015) extended this idea through his notion of a first person vicarious experience by showing that changes to practice can lead to changes in beliefs, not only through evidence of learning, but also through evidence of enjoyment. In other words, there is some evidence in Mathematics Education that practice can change beliefs. This is crucial for the research presented in this paper, which pivots around the idea that practice can change beliefs. At the same time, we need to dwell on the broader context of citizen science, within which it has been conducted.

Many researchers in Environmental Sciences acknowledge the double value of citizen science (see e.g., Taylor et al., 2022; von Gönneret al., 2023), both as an important source of large-scale data to assess ecological trends, and as a tool to foster environmental learning, civic engagement and social license for conservation. As regards the latter value of citizen science, the research presented in this paper aims at exploring how people's number sense, as well as other forms of knowledge and conceptions, are involved and which roles they play in learning activities developed in this context. With respect to the former, von Gönner et al. (2023) recall that about 60% of European rivers today are impaired, despite the EU Water Framework Directive that was established in 2000 and requires the member states to restore or maintain a good ecological status in all surface water bodies. Furthermore, von Gönner et al. (2023) observe that the EU Water Framework Directive monitoring covers rivers and streams with catchment areas greater than 10 km^2. Two thirds of the entire European river network, however, consist of small streams below 10 km^2 and play an important role for the conservation of plant, bird, amphibian and insect diversity (von Gönner et al., 2023). Due to their small discharge and often proximity to agricultural areas, small streams can be particularly affected by agricultural pesticide inputs. Thus, to effectively monitor streams and reduce pesticide and nutrient inputs as well as habitat degradation, active support from civil society actors as well as citizen engagement and compliance is essential (von Gönner et al., 2023). Moreover, previous studies have demonstrated that the rates of biodiversity loss are steeper in freshwater than terrestrial ecosystems because of human-driven pollution and habitat degradation (see Taylor et al., 2022). To this end, citizen science is worldwide recognized as an unreplaceable and urgent approach to advance freshwater biodiversity research and monitoring (Moolna et al., 2020). When looking at the riverine organisms, aquatic macroinvertebrates represent the optimal target group for citizen science activities as they are checked bioindicators for assessing the water quality according to the European (e.g. Water Framework Directive) and Italian normatives owing their taxon-specific sensitivity to physical and chemical alterations of the aquatic habitat, as well as the fact that they are easy to collect and identify (Taylor et al., 2022). In most citizen science programs focused on stream ecosystems, the method that is employed consists in sampling techniques to collect aquatic macroinvertebrate samples from the riverbed (Moolna et al., 2020), and these activities can involve citizens directly. What is new in our approach, is to combine practical activities with reflections on quantities that relate to life in the rivers. In other words, we explore how practice, knowledge about rivers and number sense can be intertwined, combining the theoretical frameworks already recalled.

The research question we aim at answering is: how does number sense emerge when people have to answer questions about rivers and sustainable behaviour with respect to water?

2 Methods

The work presented here reports on a pilot phase of a 2-years long research project and involved 28 students enrolled in the first year of an undergraduate course in Environmental Sciences, in an Italian University. Since they received no specific knowledge about river ecology and since 27 of them have a high school diploma (only one has a bachelor's degree), they can be deemed as common citizens for the aim of the research, namely they do not have any specialized knowledge of rivers or mathematics. They are 8 females, 18 males and 2 non-binary aged between 18 and 21 years, with an exception of one student who is 23 and two students who are 28 years old. At the time of the data collection, they were attending one of the last lectures of the mathematics course in the first semester, which recalls some school mathematics (ratios, percentages, Cartesian plane). The sample represents almost the totality of the students attending the course, led by the first author.

With respect to the method of data collection, we asked the students to answer 21 multiple-choice questions and, for each of them, to account for why they gave their answer, feeling free to write as much as they wanted with respect to the open prompts. For the sake of this paper, we consider 4 questions investigating number sense in the context of rivers. The other questions were about life in rivers and its biodiversity. The analysis of the answers to this set of 4 questions allows us to address the research question. The analysis process of the open-ended accounts was structured in open coding (see also Mayring, 2015). The analysis of the answers to the multiple-choice questions is based on frequencies.

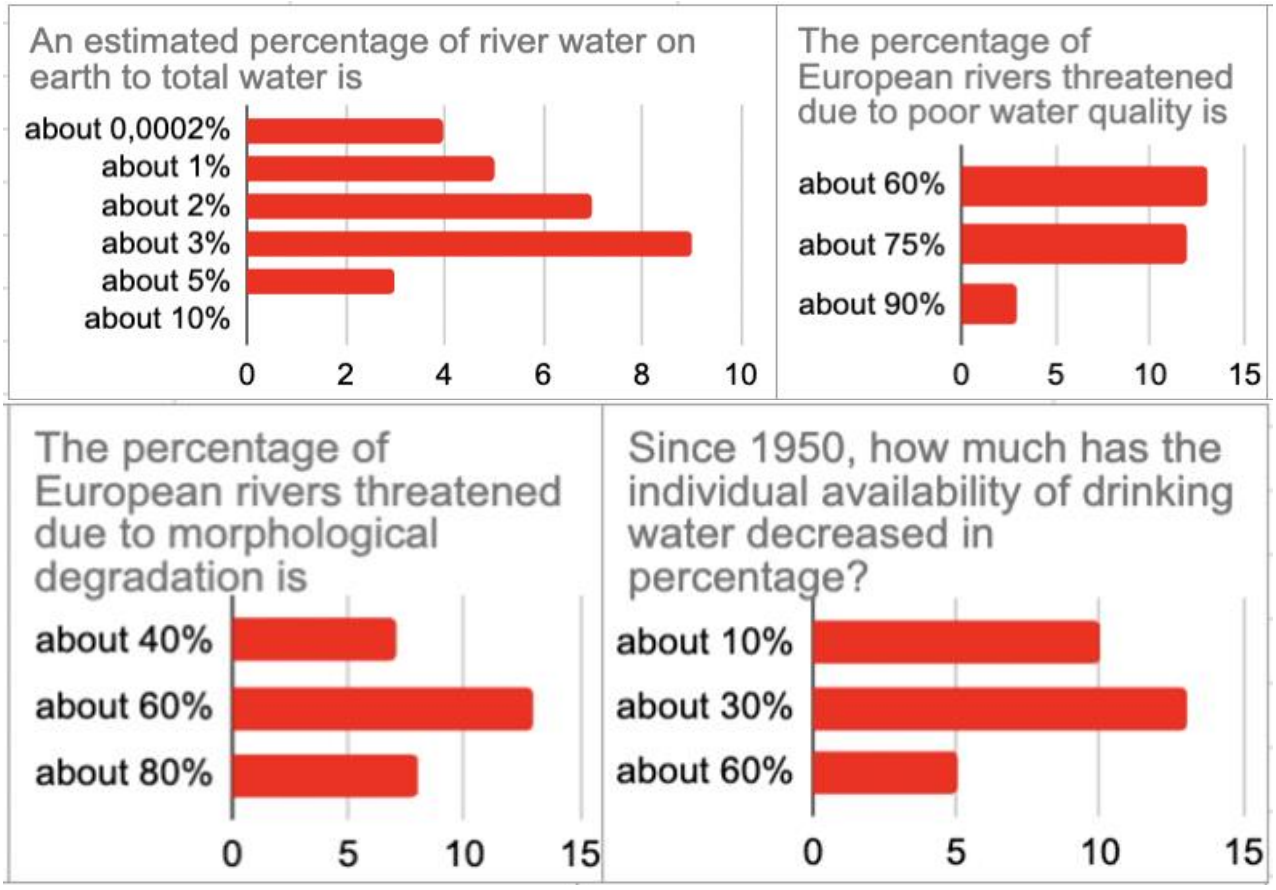
In order to write the multiple-choice questions to investigate number sense in the context of water exploitation and pollution, we were inspired by Hans Rosling's, Ola Rosling's, and Anna Rosling Rönnlund's *Factfulness*, an approach that aims at unfolding the conceptions people hold about the world in terms of quantities, ratios and relative frequencies of relevant phenomena (Lefsrud, 2018), approach that is in line with the framework within which we developed our research at the boundary between mathematics education and environmental education. Moreover, we claim that the questions involve number sense, because respondents were asked to estimate the percentage of rivers affected by degradation, or the percentage of river water on Earth, or how much the availability of drinking water has decreased in the last 70 years. In line with the style of *Factfulness* questions, the correct answer is also the most optimistic one, for example it is the lowest percentage of impaired rivers among the proposed alternatives. We were also inspired by the questions developed in the study by Grima *et al.* (2010) to the context of the river. In that study, correct information about life in and with rivers is checked and the alternatives refer to possible misconceptions that may have been developed within groups of people living, e.g., in big cities and experiencing only rivers that are artificially altered, or on the contrary practicing fishing. Number sense is investigated by asking the respondents to choose among percentages that can best represent a phenomenon regarding rivers. This implies that the research investigates in particular number sense when percentages are involved. The first question asks about the percentage of river water over total water on Earth and number sense is investigated by prompting respondents to discern among small percentages (the correct answer is 0.0002% and the alternatives are 1%, 2%, 3%, 5% and 10%). As number sense is defined as an understanding of quantities, we investigate how people understand small quantities. As number sense concerns also how quantities are related to each other, we investigate how people related the amount of river water and the total amount of water on Earth. The other three questions involve bigger percentages, but the sense and the aim are the same. Students' responses have been coded as: (a) s/he said s/he knew the answer, (b) s/he did not reply, (c) emergence of beliefs about river water, (d) mathematical beliefs, and then the codes have been analysed. The three authors of the paper discussed intensely about the codes and their analysis, until they reached consensus.

3 Data analysis discussion of results

We now show: (a) the percentages of the answers given to the multiple-choice questions and (b) the accounts the participants gave for them in the open prompts. We start with number sense in the context of river water (Figure 1, top left). The estimated percentage of river water on earth is 0,0002% of the total water, but only 4 students selected it and in their open answers one wrote that he knew the answer, one guessed, one reasoned that water in rivers is much less than the total water on earth and one that 2% is the percentage of drinking water on Earth and hence 0.002% is the only reasonable answer for the portion of river water in her view. If we read these statements with the lens of our framework, we say that scientific knowledge emerges—not conceptions. Of those who gave a wrong estimate of 1%, 4 students wrote that it seems to them the right percentage and one wrote nothing. Those who gave an estimate of 2% (that is the estimate of the total freshwater on Earth) did not motivate their choice, only 2 ones thought that there is much less river water than other water. Those who gave 3% thought that the percentage of river water is low but not that low (3 students), while 2 students declared that they guessed and the remaining 4 ones did not write any account for their answer. The 3 students who gave 5% as an answer declared to be unsure. Conceptions about the amount of river water emerge, but the most interesting data for us is the absence of justification and/or students saying they are unsure, because we interpret this as mathematics-related affect emerging with blockage and lack of confidence. As number sense is defined as an attitude to use numbers in the real world, we can see a lack of number sense in not answering.

The correct answer to the question about poor water quality (Figure 1, top right) is that 60% of European rivers are threatened: 13 students selected it and 12 of them motivated their choice by saying that the other options are too high. They suspect the percentage is high, but not dramatically high. One student said that he hoped it is this one. No one said they knew the answer, but affective clues like hope for not being worse emerge in the accounts for the correct answer (and this informs *Factfulness* framework). Among the 12 students who selected 75%, one student noted that the percentage is increasing because of drought, other 2 students said that clean rivers are very rare, 2 guessed and the others did not provide an open answer. Of the 3 students who selected 90%, one said that the effects of the recent norms might not be visible, one said that he thought rivers are very polluted and one imagines that almost the totality of rivers are polluted. Beside the fact that 15 answers are incorrect, we comment that it emerges that participants know that rivers are among the most exploited water resources and therefore most subject to alteration. Contrary to the first question, in this case the respondents show willingness to apply numbers, thus in this case number sense does emerge. Knowledge of the direct human-river relationship also emerges. To this regard, the sense of percentages is higher than reality: pessimism in *Factfulness* terms is confirmed.

Figure 1. The answers to the 4 questions investigating number sense.



The percentage of EU rivers threatened for morphological degradation (Figure 1, bottom left) is about 40% and all the 7 students who selected this answer declared that they hope it is that low. Also for this question, affect emerges to support answering correctly. The 13 students that selected 60% wrote that they have confidence in the recent norms to reduce river degradation, or that they suspect that the percentage is slightly above 50%, or that they believe it is quite high. In students' words, beliefs and confidence are the elements on which they ground their answers. The 8 students who selected 80% think that it could be almost the totality of the rivers and one mentions that the effects of the recent norms are still not observable (implying that they think the percentage would decrease in the future). Being knowledge based on experiences and being conceptions fragmented, according to Grima *et al.* (2010), the relatively high proportion of students who selected the answers 60% and 80% prompts us to interpret such high percentages in the following terms: if one lives downtown and the only rivers known are all channelized rivers with concrete banks, it is likely that their answer will be oriented towards higher percentages. Guskey (1986) comes to help us interpreting this, as practice shapes beliefs, which in turn affect students' answers. If knowledge is, according to this theory, based on experience or perception, then also people who do not live in close contact with the rivers but know them only through television/internet services and news (which are normally biased towards sensational news stories or environmental disasters) may therefore think that the situation is worse than how it really is.

The availability of drinking water (Figure 1, bottom right) has decreased by 10% since 1950 and 4 out of the 10 students who selected this option declared that they think that this is monitored (implying that, without norms, the situation could have been worse), one guessed and the others did not provide an answer. The 13 students who selected 30% declared to have chosen an intermediate value and the 5 students who selected 50% wrote that they suspect that it has dramatically decreased. They also mention pollution as a cause for reduction in drinking water. 18 out of 28 respondents are pessimistic, in Factfulness terms, in this case. We note that conceptions about water, not conceptions about percentages, emerge. We hypothesize that this pessimism is a consequence of the effects of climate change (and of the serious episodes of drought that have been experienced in Italy in the last 2-3 years).

Towards answering the research question, table 1 summarizes the results, reporting the percentages of correct and incorrect answers to the four questions, and the accounts the students gave for each of them.

Table 1. Percentages of correct and incorrect answers to the four number sense questions about river water, in order from the smallest percentage of correct answers to the biggest one.

	Percentage of river water		**Morphological degradation**		**Drinking water decrease**		**Poor water quality**	
Frequencies of answers	**correct 14%**	**over-estimate 86%**	**correct 25%**	**over-estimate 75%**	**correct 36%**	**over-estimate 74%**	**correct 46%**	**over-estimate 54%**
Written accounts	know the answer	do not justify (the majority)	hope	think it is above 50%	it is monitored	chose an intermediate value	suspect it is high, but not too high	drought
	guessed or tried	guessed		effects of recent norms are still not visible	guessed	suspect it is dramatic	hope for not being worse	clean rivers are rare
	reasoned							effect of recent norms are still not visible

Wondering how number sense emerges when people reason about river water, we can start focusing on the question about the percentage of river water with respect to the total water on earth. Among those who answered correctly, some knew the answer, while others guessed or reasoned: this shows some evidence, in our view, that conceptions are an amalgam of knowledge and beliefs, and that sometimes they sustain correct views of rivers. One of the respondents also showed good knowledge of percentages, but we should also be aware that the students who answered correctly about the percentage of river water over total water is a minority, while 86% of students overestimated it. We notice that students have a good sense of percentages, but they are unable to connect it to their experience of rivers. We believe that this may be partially driven by perception because, despite their low percentage, rivers are heavily exploited for human needs (Dudgeon, 2019). Namely, river water is the most known and used by humans, compared to other sources of water, hence it seems plausible that we tend to overestimate its presence.

Knowledge about the percentage of rivers that are affected by morphological degradation is slightly better, and hope emerges as an affective trait that sustains correct answers. We interpret the finding that 75% of students overestimated the percentage of rivers affected by morphological degradation as if the direct experience of rivers for those who live in the cities and the news from media might have promoted a certain view of rivers, i.e. all but natural. At the same time, among those who gave an overestimate, we noted that they have a good sense of percentages and this is in line with Liljedahl's (2015) observation about number sense that what we need is basic mathematics—there is no need for more mathematics or more complex mathematics, but mathematics should be more strongly connected to the real world. In fact, these students show knowledge of percentages but are unable to connect it to the real situation of rivers, as school is fairly disconnected from the real world. Similar conclusions can be drawn from looking at the answers to the question about the decrease of drinking water per capita, especially with respect to the effects of media. And also for the question about the percentage of rivers affected by poor water quality, we can see that conceptions emerge as an amalgam of knowledge (i.e., knowledge of the recent normative), experience (e.g., drought) and beliefs about rivers, which are conceived of as polluted more that how much they effectively are.

4 Conclusions

Results from our investigation on citizens' number sense in the context of rivers reveal that people think that the percentage of river water is higher than it actually is, that rivers with good water quality are less than the actual ones, that more rivers than the actual ones are affected by morphological degradation and that the percentage of drinking water per capita has dramatically decreased in the last 70 years, more dramatically than how much the actual trend reveals.

The sample was small, and only young people have been interviewed. Beside the small sample size, another limitation of this study is the use of multiple choice questions, whose value in affect-related research had been questioned on several occasions. Adding open-ended justifications for why choosing the answers partly mitigates the limitations of this methodology. Last but not least, a third limitation is the subjectivity of the interpretations. It has been mitigated by intense discussions among the three authors, who have different backgrounds: one is a researcher in Mathematics Education, one is a researcher in biology and an expert in Citizen Science, and one is a student in Environmental Sciences. The different backgrounds of the authors can be taken as a way to overcome biased interpretations due to the influence of a specific field of research.

Despite its limitations, we believe that the merit of this contribution is, however, to show how the method can work and to unveil students' conceptions. Also, the number of questions was very limited, but this limitation is due to the fact that longer questionnaires are generally avoided by citizens. We, as a matter of fact, need to rely on a little number of questions to measure citizen number sense and knowledge about rivers. The number of questions being limited allows us to ask respondents to account for their choices and it represents for us a source of data to understand how people think and choose with respect to phenomena related to rivers, as well as to get the sense of mathematical knowledge they activate in number sense tasks.

We can consider this study as explorative and argue that it is necessary that the students develop a direct experience of rivers, in order to enhance their knowledge of the world and to better connect mathematical knowledge to their experiences in the world, which is the very core of number sense (Liljedahl, 2015). This is even more important, when influences of the media and of students' experiences with rivers in cities emerge as shaping their pessimistic views.

Research ethics

Author contributions

C.A.: conceptualization, literature review, supervision, methodology, writing—original draft preparation, writing—review and editing
A.D.: literature review, data collection, formal analysis, funding acquisition, project administration, writing—review and editing
C.S.: data collection, data analysis, writing—review and editing.
All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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