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Exploring the role of conceptions and views of mathematics in shaping the perception and interpretation of statistical graphs

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Abstract: It is evident that climate change, pollution, population growth rate, and environmental and social issues have become prominent subjects in recent years. Statistical graphs have emerged as the predominant method for scientists to communicate data regarding these phenomena. Within the Factfulness project, the incidence of certain facts interpreted on the basis of personal conceptions is presented in graphical form, which may present a different narrative to that which individuals believe to be true, thus purportedly correcting the most common biases. However, research in the field of Mathematics Education has indicated that individuals frequently encounter challenges in comprehending graphs. The present study investigates the role of affect-related variables in shaping the manner in which individuals approach graphs. A sample of 80 undergraduate students in Psychology was considered for this study. The students were invited to: (i) respond to a Factfulness questionnaire concerning environmental issues, (ii) read and interpret graphs from which they could infer the correct answers to the questionnaire, and (iii) rate the aesthetics and the transparency of the graphs proposed to them. The analysis of the participants' comments and their appreciation of graphs provides a foundation for enhancing the communication of environmental issues through statistical graphs, with a particular focus on affect-related aspects.

Keywords: conceptions, mathematical views, socio-environmental issues, statistical graphs

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1 Introduction and problem statement

Prominent researchers in Mathematics Education (e.g., Coles et al., 2013) invite us to teach mathematics as if our planet matters. This entails bringing into mathematics classes issues that pertain to problems such as climate change and developing knowledge and competencies that allow students to interpret such phenomena. Mathematical graphs are well acknowledged to be an effective tool for environmental scientists to convey information about issues such as pollution, increasing temperatures, and climate change, especially when interacting with people outside the scientific community (Grainger et al., 2016). In particular, Rosling et al. (2018) show that reflecting on graphs entails becoming aware of several issues that go beyond the graphs themselves.

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In April 2018, the book Factfulness (Rosling et al., 2018) was published: it examines widespread "mega misconceptions" about global trends and explains why people often misinterpret data particularly when influenced by media narratives about the state of the world. The book opens with a series of 13 multiple-choice "fact questions", such as "what is the life expectancy of the world today?" (p. 3) which readers are prompted to answer. The questions cover various aspects of reality from recent years, including poverty, demography, environmental and social issues. The results of such fact checks are striking: the majority of people who answer the questions get most of the answers wrong (with error rates of up to 98% on certain questions), regardless of their social context or education level. Even journalists and documentary filmmakers who specialise in the topics covered reach rates of error higher than 33% (the rate corresponding to perfect random choice).

Amico et al. (2025) draw on the Factfulness project and identify the various conceptions people hold when asked to rate the incidence of some environmental phenomena, such as the extent of protected marine areas, and the annual numbers of oil tanker spills since 1970s. These authors focus on three instincts, identified by Rosling et al. (2018), which can help us examine why people develop misconceptions about the world, namely the "gap instinct", the "generalization instinct", and the "size instinct". The gap instinct is the tendency to see the world divided into two main categories; the example that Rosling et al. (2018) gives concerns the level of wealth of the population of the various states of the world, which is commonly divided into rich and poor; the problem with the gap instinct is the loss of the majority, namely the large proportion of the population that exist between the two extremes. To overcome this tendency, the author argues it is necessary to avoid comparing exclusively the averages of two populations. Instead, we should take into account measures such as the median and, especially, the entire frequency distribution, allowing us to identify where the majority actually lies. Within mathematics education, students' understanding of mean, median, and mode was the focus of an extensive review made by Garfield and Ben-Zvi (2007), who show a lack of conceptual understanding beyond the algorithms used to determine each measure. For instance, many students know the algorithm for finding a mean, but do not know, or pay attention to, the mathematical properties of the measure. Thus, students may develop misleading conceptions about these measures (Bond et al. 2012). We underline that the main point is not about conceptions being correct or wrong, but about the complex role that instincts play in relation to knowledge.

According to Rosling et al. (2018), the generalization instinct is responsible for the loss of exceptions. To describe the world accurately, it is necessary to remember that reality lies on a continuum, the neat categories we often impose on it can be arbitrary and/or fragile and can obscure the diversity within groups and the similarities across them (Rosling et al., 2018). Questioning the arbitrary division of a population is a good way to counter such tendencies and highlight features that would otherwise be hidden, to question whether what is true in one group may or may not be true for another (Rosling et al., 2018). Again, we are not talking about being correct or wrong, but we take this as a description of how instincts can deeply influence the way people see and interpret certain facts (Philipp, 2007).

The size instinct deals with the tendency to focus on absolute values without a proper sense of those values in context. To counter this tendency, Rosling et al. (2018) suggests we compare single values with some other relevant values, such as historical ones. Dealing with proportions and knowing how to apply them to the real world is a decisive skill to make big numbers more graspable; according to Rosling et al. (2018), for a correct understanding of data, it is important to differentiate between rates and amounts. It seems that mathematical beliefs, developed in school years, push individuals to focus more on absolute numbers and to pay less attention to rates (Garfield & Ben-Zvi, 2007).

Within the Factfulness project, statistical graphs play a central role in dealing with erroneous conceptions. However, Ainley (2000) warns us that graphs are not always transparent to those who read them. In accordance with previous discussions (e.g., Doria & Amico, 2023), transparency in a general sense is the quality that allows for easy perception or detection of specific information. Doria and Amico (2023) also consider aesthetic appreciation of graphs as a central idea. A meta-analytic review by Thielsch et al. (2019) highlighted that the visual aesthetics of websites, software and other interfaces have a positive impact on user performance, enhancing attention and concentration. As articulated by David and Glore (2010), “design and aesthetics profoundly influence how users perceive information, learn, assess credibility and usability, and ultimately assign value to a product” (p. 3). From these words we can infer that conceptions, as well as transparency and aesthetics, play a central role in both approaching and interpreting graphs. In this paper we investigate how conceptions as well as perceptions of transparency and beauty of statistical graphs emerge when students are asked to interpret graphs and to rate their transparency and aesthetic merit. The theoretical framework is thus threefold and builds on literature relating to: (i) conceptions; (ii) transparency and aesthetics of graphs; and (iii) instincts, which in the field of Mathematics Education can be investigated within the constructs of beliefs, conceptions and mathematical views. In fact, perceptions of aesthetics and transparency trigger mathematical views (Doria & Scalvini, 2024). The research question we aim to answer is: What are the students’ perceptions of aesthetics and transparency, interpreting these from a framework of mathematical views, conceptions and beliefs?

2. Theoretical background

The Factfulness project, as well as research findings from mathematics education, have inspired this study. Thus, the theoretical background of our research pivots around key theoretical constructs, which have been prompted by the initial reflections that emerged from the research findings recalled in the introduction. Firstly, we discuss conceptions in mathematics education. Secondly, since Factfulness relies on graphs to convey information, we discuss the constructs of transparency and aesthetics to investigate how students approach graphs. We link this discussion to the emergence of mathematical views.

2.1 Conceptions

Conceptions are seen as clusters of beliefs. 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), 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 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.

The construct "conceptions" can be meant as an umbrella term, 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). One aspect of a belief system relevant for our research is that beliefs are organised in clusters that are not necessarily logically connected. The fact that beliefs can be contradictory (Fives & Buehl, 2012) allows the possibility for people to hold beliefs that belong to different clusters. Skott (2015) suggests, however, to interpret possible contradictions in individuals' belief systems not merely as incoherences, but rather to consider the different contexts in which beliefs are evoked and taking into account that they cannot be exhaustively described by one cluster of central beliefs. These considerations shed light on two intertwined features of beliefs: they are subjective in nature and individually held, but at the same time they are (or can be) socially and contextually shaped. The context plays a crucial role in evoking beliefs (e.g. Fives & Buehl, 2012), and hence conceptions.

2.2 Transparency and aesthetics of statistical graphs, and views of mathematics

Graphs are mathematical entities that are comprehensible through the interpretation of their representations rather than in a direct manner. In other words, grasping the concept within a graph involves a cognitive process that connects the signifier (information) to its signified (the graph) (Duval, 2006). Roth (2003) posits that “graphs, as entities, do not exist in isolation; rather, they are intricate networks that integrate various components and processes” (p. 305). Enhancing these cognitive processes, as discussed by Roth, could potentially enhance the transparency of graphs. The term transparency refers to the characteristic of seeing through an object, that is the ease with which an observer can access the information hidden by what is visible in the foreground. There is an object, definite and circumscribed, and a story ‘lying beyond’ that; the term transparency denotes how easily the user can access such hidden significance. Lave and Wenger (1991) describe transparency as the combining of two characteristics: invisibility and visibility. In order to explain this dual nature, they resort to the metaphor of the window: a window is highly visible in contrast to the wall that contains it, but the hidden meanings, represented by what lays behind the window, is only clear if the glass is invisible enough (Ainley, 2000, p. 366).

In the case of graphs, transparency is a characteristic that determines how easily data can be read (e.g., Ainley, 2000), the role of the window is played by the graph and the hidden meaning is represented by the detectable information. The slope of the curve, the relationships between the variables, the variation with time are all examples of the information hidden behind a graph. Roth and McGinn (1996) consider the relationship between reality and graph as bidirectional, because it is assumed that a literate person can read the specifics of the walk from the graph or construct a graph after making (or imagining) a walk. However, there is evidence that this relationship must be constructed in the same way as “the relationship between the word ‘cat’ and some furry creature that meows” (p. 96).

These considerations, however, entail that students become literate in reading graphs. This is connected to Glazer’s (2013) argument that, in order for students to use their knowledge and acquire critical thinking, it is necessary to do more than study the core subject. This holds in general, for mathematics, and in particular for graphs. Coles (2023) proposes a curricular innovation for mathematics, more linked to the real world, namely connected to data and experiences; we think that Coles’ suggestion should also apply to those tools that mathematics makes available to describe the world in which we live. Graphs are especially important for communicating information to the public, for instance, when explaining climate or environment data and associated changes that occur around the world every day (Grainger et al., 2016). However, Ainley (2000) warns us that data is not always accessible from a graph for those who read it. This could have dramatic consequences when environmental, social, political or economic problems need to be communicated through graphs: as Demeritt and Nobert (2014) observe, ineffectiveness of communication through graphs may prevent comprehension and, thus, create misunderstandings and inconsistent or biased messages.

Doria and Scalvini (2025) provide evidence that beliefs about mathematics play a central role in shaping how students approach the transparency of graphs. The theoretical framework adopted in their study is the one developed by Grigutsch et al. (1998) around the construct of mathematical world views. According to Erens and Eichler (2019), who recently operationalised Grigutsch et al.'s (1998) work, it is possible to outline four different mathematical world views (see also Liljedahl et al., 2007): 1) a process-oriented view that represents mathematics as a creative activity consisting of problem solving using different and individual ways; 2) an application-oriented view that represents the utility of mathematics for real world problems as the main aspect of the nature of mathematics; 3) a formalist view that represents mathematics as characterized by a strongly logical and formal structure; and 4) a schema-oriented view that represents mathematics as a set of calculation rules and procedures to apply for routine tasks. Doria and Scalvini (2025) showed that, when students are asked to account for why they find a graph transparent, about a quarter of them give replies that can be coded within a formal-oriented view, and in particular to the clarity of the graph. Another one third of replies are coded within a schema-oriented view, since they refer to the immediacy of interpretation; the easiness with which it can be read; the use of basic mathematical objects (like rectangles); the fact that it is a graph they are more used to; or that is the most linear one. Statements that can be coded within an application-oriented view emerge in about a quarter of the cases, and they refer to adherence to data; how much the differences are made visible; or to the underlying trend shown in the real-world situation that the graph is aiming to represent. Doria and Scalvini (2025) conclude that a balance of formal-oriented, schema-oriented, and application-oriented views emerge when the students are invited to justify their choice of a graph they find transparent. The authors further comment that, since the schema-oriented view is the prevalent one at school, it seems that when students have to judge a graph based on its transparency, a portion of them refer to their own schooling and the beliefs developed during this time. This might be interpreted as overhanging beliefs, as they have been defined by Daskalogianni and Simpson (2001). From one side, it seems that graphs are strongly bonded to both the context and the subject they emerge from (see also Ivanjek et al., 2016), and at the same time their readability heavily depends on the beliefs about mathematics held by those who read and interpret them.

Moreover, Thielsch et al. (2019) observe that a fundamental feature of graphs is their aesthetics, "users not only feel better if they use aesthetically pleasant interfaces, but, on average, they also perform a little better as well" (p.208). Aesthetics, a term derived from the Greek "aesthesis", meaning perception, represents a philosophical construct imbued with profound reflections on art, beauty and sensorial experiences (Zingarelli, 2020). It is not only a matter of personal experience but involves the philosophical and conceptual understanding of what arouses emotions and appreciation in the observer: studying the reasons behind such perceptions represents the very meaning of aesthetic research. In his Critique of Judgment, Kant (1790) argues that beauty cannot be reduced to specific rules or criteria, but is rather a subjective experience, based on the harmony between intellect and imagination. In Lectures on Aesthetics, Hegel (1835) maintains that the aesthetic experience is a phase of the evolutionary process of the spirit, linked to the understanding of the intrinsic meaning of a work of art. In general, therefore, we can say that the function of beauty is to make the viewer experience pleasure. Research in mathematics education has resorted to different meanings of aesthetics in mathematics, but from the previous considerations it becomes clear that in our case we consider aesthetics as beauty. Sinclair (see e.g. 2008) has dedicated substantial research effort in providing evidence about the importance of aesthetics for the development of mathematical thought, and she maintains that scholars have discussed varying ways in which aesthetic judgements arise in mathematics, often using words such as “elegance” and “depth”. Various interpretations of mathematical beauty have historically been developed (Sinclair, 2008). According to Fang et al. (2023), mathematical beauty is an intuitive phenomenon that combines elements of science and humanities and its key characteristics include: the elegance of mathematical symbols and theorems, balance and proportion, coherence in mathematical concepts and thought processes, the uniqueness and peculiarity of certain mathematical ideas, and the logical and abstract aspects of mathematics. Fang et al. (2023) stress the growing recognition of mathematical beauty in education, to suggest that mathematics teaching should not only focus on knowledge accumulation but also foster students' comprehensive development and appreciation of mathematical aesthetics. Furthermore, integrating scientific and humanistic values into mathematics education can enhance students' aesthetic literacy and interest in the subject (Fang et al., 2023).

What does all this mean in the context of statistical graphs? Doria and Scalvini (2025) provide evidence that more than one third of the answers given by students when they account for why they find a graph beautiful can be coded as within a formal-oriented view: the students value order, neatness, clarity and precision. About 10% of responses are coded as pertaining to a schema-oriented view, and in one case the appreciation is related to closeness with the school practice. Less than 5% of answers can be coded as within a process-oriented view, for its focus on the fact that all the people can access and use mathematical ideas, and less than 5% are coded as application-oriented view, for its focus on real data. Doria and Scalvini (2025) conclude that a formal-oriented view, namely a mathematical world view that pivots around formalism, emphasising order, precision and clarity, emerges significantly more than other views when students have to justify their choice of a beautiful graph.

3. Methods

Data collection in this study is based on a didactical activity that consists in student participants answering eight Factfulness questions, looking at the graphs from which they can infer the correct answer to each of those questions, and then rating the transparency and the aesthetics of the given graphs. This activity has been presented during a series of lectures on descriptive statistics and on how to create statistical graphs as well as on how to read and interpret given statistical graphs. The eight (out of 13) Factfulness questions were taken from the project website, and selected because they pertain to environmental issues, and because they have previously been given to a large sample of interviewees. The graphs shown to the students also come from the Factfulness website. The activity lasted 90 minutes.

In this paper, we consider responses to two particular Factfulness questions that relate to the quality of marine water conservation. The first question and possible answers are:

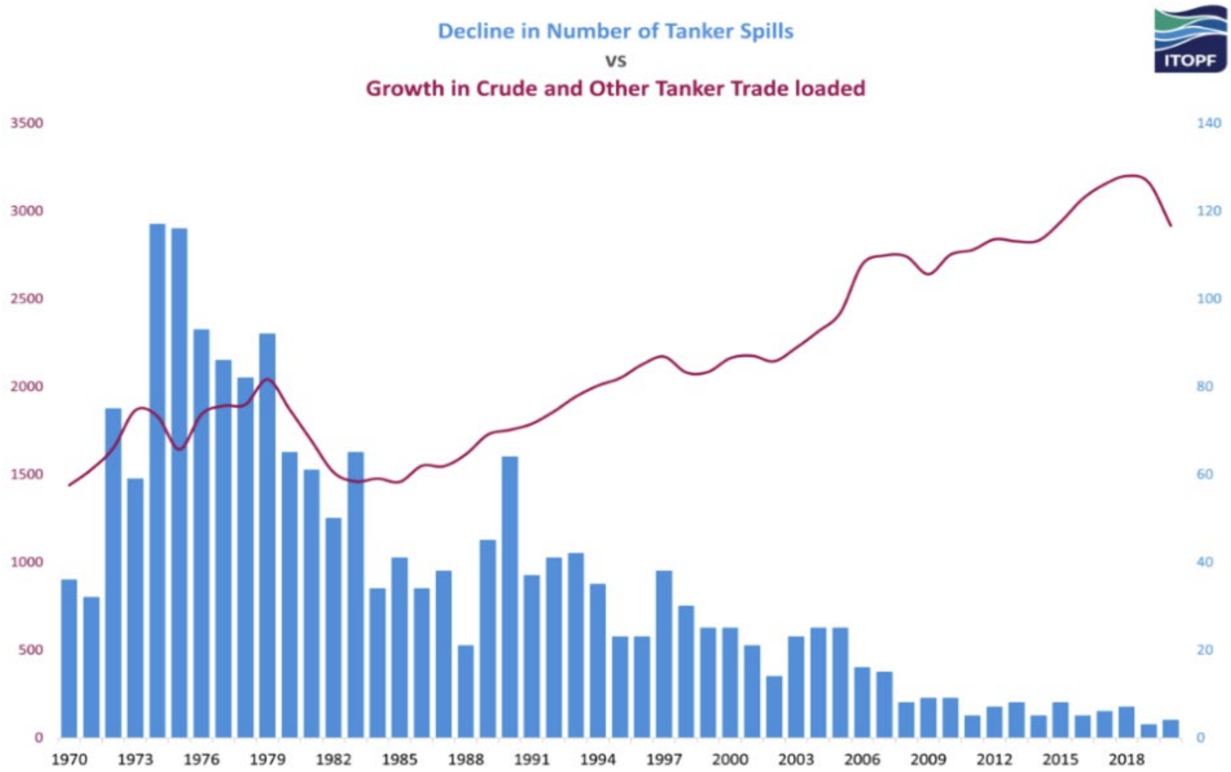
> What has happened to the number of oil spill accidents from tankers since 1970?
> (a) it has increased tenfold;
> (b) it has remained almost the same;
> (c) it has decreased tenfold.

The second question and possible answers are:

> Compared to 2016, how has the surface area occupied by marine protected areas around the world evolved?
> (a) it has decreased by 75%;
> (b) it has remained almost the same;
> (c) it has increased by 75%.

We can notice that one option is always pessimistic, and serves the purpose of capturing the pessimistic views of the people interviewed (Rosling et al., 2018), another option is intermediate, and the third is optimistic and is the correct choice.

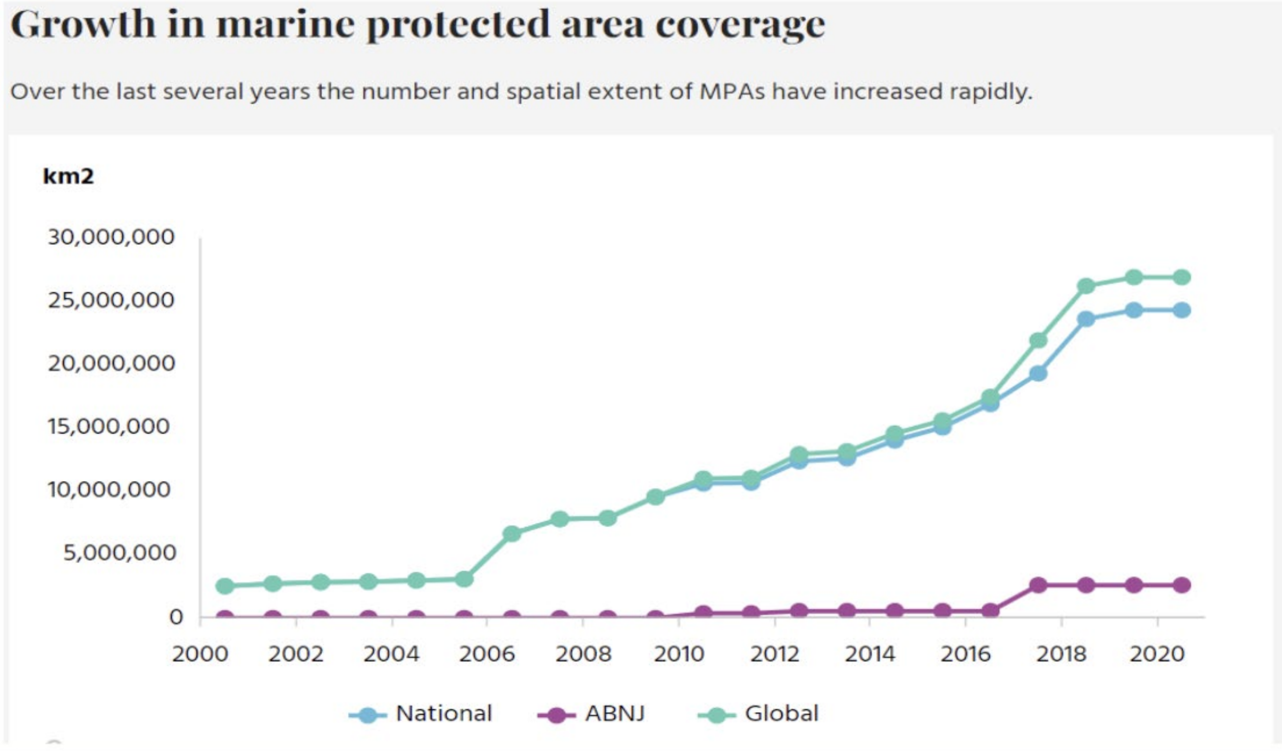
Figure 1. The bar graph showing the trend of tanker spills since 1970. Source: ITPOF https://www.itopf.org/knowledge-resources/data-statistics/oil-tanker-spill-statistics-2024/



Rosling et al. (2018) found that a substantial majority of people, when posed the multiple-choice questions, select the incorrect or overly pessimistic option. The graphs in Figures 1 and 2 are the ones that Rosling et al. (2018) show to respondents with the aim of correcting their alternative conceptions. We selected these graphs among the ones proposed by Rosling et al. (2018), because as a bar graph and a line graph, they are the two types of graphs that were rated highest and the lowest respectively, in terms of transparency and aesthetics (Doria & Scalvini, 2024). The bar graph is rated most transparent, if it is shown alone, whereas the line graph is rated as the least transparent (Doria and Scalvini, 2024). In Figure 1, the two graphs are overlapped, and we aim at exploring if and how students' perceptions about transparency change in this case. There is an additional difficulty, that is the presence of two scales, one for the bar graph, which is to the right, and one for the line graph, to the left. To understand that the number of oil spills from tankers since 1970 has decreased tenfold, one should combine the two pieces of information. One is that in the 1970s there were approximately 120 spills per year, and the load capacity of tankers was approximately 2000, so overall every year 240,000 litres of oil was spilled into the oceans. The other one is that nowadays there are approximately five spills per year, and the load capacity of tankers is approximately 3000, so overall every year 15,000 litres of oil is spilled into the oceans. The conclusion is that the overall quantity of oil, as well as the number of spills, had decreased tenfold.

In Figure 2, a line graph is presented. According to Doria and Scalvini (2024), this kind of graph is rated low for transparency, however, the increases in marine protected areas seem quite immediate, as the lines in the graph increase. We aim at exploring these surprising perceptions and the interpretations of this graph, in this particular context.

Figure 2. The line graph shows the trend of marine protected areas over the last years. Data source: O'Leary et al. (2018).



For both graphs in Figures 1 and 2, we can also notice that they prompt the respondents to focus on distributions and on relative quantities (Rosling et al., 2018), rather than on absolute numbers which can help in eliciting correct conclusions about statistical data (Garfield & Ben-Zvi, 2007).

In this study, the students were invited to study the graphs, to write down what they have understood from them, and to rate the graphs in terms of their beauty and transparency, accounting for these ratings.

We structured the data analysis into a series of phases. First, we considered the interpretative statements that students produced after studying the two graphs (Figure 1: tanker spills, and Figure 2: marine protected areas). These statements were analysed to determine whether each graph was understood correctly, and to what extent participants were able to articulate a meaningful interpretation of the visual data. We also examined the numerical ratings that participants attributed to each graph's transparency and aesthetics, on a scale from 1 ("not at all") to 5 ("completely"). These ratings provided an overall sense of perceived clarity and visual appeal. We focused on the open-ended accounts that participants provided to explain their ratings. In analysing the participants' answers, we adopted a qualitative content analysis approach (Mayring, 2015), with an interpretive lens informed by the framework of mathematical views proposed by

Grigutsch at al. (1998) and operationalised in recent work by Erens and Eichler (2019). Our aim was to explore the beliefs and conceptions students mobilised when interacting with two specific graphs from the Factfulness project. The four categories are:

- Formalist-oriented view: emphasis on precision, order, clarity, and correctness of representation. An exemplary statement that elicits this view can be: "The graph is tidy and precise, with well-separated values and clear lines."
- Application-oriented view: focus on real-world relevance and the ability of the graph to reflect meaningful or practical information. An example of a statement for this view is: "It clearly shows the trend in marine conservation efforts over the years."
- Schema-oriented view: reliance on familiar structures, routines, and school-taught graphical conventions. Among the examples, one can be: "It's easy to read because I've seen bar graphs like this in high school."
- Process-oriented view: recognition of graphs as dynamic tools for exploration, creativity, or sense-making. An exemplary statement is: "Understanding the graph requires looking for patterns and making sense of what's happening behind the data."

Each justification was independently coded by one of the authors; disagreements emerged in less than 10% of cases, and were resolved through discussion until a consensus was reached. Inter-rater reliability was not measured, as there was qualitatively a high degree of agreement among the researchers. Finally, we revisited the initial interpretations of the graphs (phase one) to assess whether participants who rated a graph as "transparent" actually demonstrated an accurate understanding of the data presented. This allowed us to connect perceived transparency with effective interpretation. Throughout the analysis, particular attention was paid to the co-occurrence of certain mathematical views with specific aesthetic or transparency ratings, as well as the emergence of affect-related language in participants' responses.

The participants in the study were 99 students attending an undergraduate course in Psychology in an Italian university during the academic year 2024/25. They were at the beginning of the first semester of the second year and attending the first lectures of a course in Statistics, held by one of the authors of this paper. A large majority of them are female and do not have a strong mathematical background, nor a strong scientific background. For this reason, the sample can be representative of the general population (e.g., not restricted to those from a strong science, technology, engineering or mathematics (STEM) background, which could have biased their capacities to interpret the graphs, as well as the perception of transparency and aesthetics). Moreover, Psychology students may have a greater propensity to reflect and write when asked to comment on conceptions, and this can be a strength. The students' responses were collected anonymously, and they were not used as part of any formal assessment, in order to avoid social desirability bias.

4. Data analysis

In this section, we analyse the open answers given by the participants about how they interpreted the graphs about tanker spills (Figure 1) and marine protected areas (Figure 2), respectively. We also look at the rates they gave to aesthetics and transparency of the two graphs, and to the accounts they provided for why they selected a certain degree of aesthetics and transparency, coding the emerging mathematical views according to Erens and Eichler (2019). We start with the bar graph on tanker spills.

4.1 Interpretations of a graph on oil tanker spills

To recall, we first showed the graph in Figure 1 to the student participants, then we asked them to write down the information they could read from it. Nine participants gave a wrong answer, and we report the one given by Francesco, who gave a rating of 5, i.e. the maximum, for aesthetics (accounting with "colourful" for his choice), and a rating of 2 for transparency (accounting with "One does not immediately get the information from the graph" for his choice). We also note that we can code Francesco's account for transparency as an emerging formal-oriented view of mathematics, with a focus on clarity. A formalist-oriented view, according to Erens and Eichler (2019), assigns a central role to precision, order and clarity within mathematics, hence focusing on (not) getting the information from the graph immediately represents a focus on (lack of) clarity. With respect to the interpretation of the graph, he wrote:

> **Francesco**: The number of tanker spills has increased.

From Francesco's answer, we can see that he liked the graph, but he did not find it clear, and gave a wrong interpretation of it. Francesco notes that the number of tanker spills increased, namely he focuses on the violet line reporting the trade, and not on the blue bar graph, where the information about the tanker spills is provided. The interpretation of Francesco's error could find its cause in an erroneous reading of the graph, or, according to the Factfulness perspective, in the identification of the line graph as correct, because it confirms his misconception. Bar graphs have been identified as the most transparent (Doria & Scalvini, 2024), thus this finding shows that it is not always the case, but it also shows that students can find it difficult to integrate information from two different graphs (Garfield & Ben-Zvi, 2007).

Another three students who interpreted the graph incorrectly assigned a rating of 3 for aesthetics and 1 or 2 for transparency. Arianna commented:

> **Arianna:** It's all glued together, but I think the choice of the bar graph is right because it allows you to see the differences better.

In this case Arianna shows a greater attention to the graph than Francesco, identifying the ease of reading of a bar graph as higher than the line graph, but still makes mistakes: the dramatic instinct seems to prevail and in her response she signals the wrong trend, that is, the one that confirms her misconception. This particular group of students have weak mathematical backgrounds. A lack of basic statistical knowledge might have influenced their capacity to interpret the graph correctly. In terms of mathematical views, we interpret Arianna's statement as belonging to a formal-oriented view, as she focuses on (lack of) precision, saying "it is all glued together", and clarity, saying "it allows you to see the differences better".

Another four participants, among the ones who gave an incorrect interpretation of the graph in Figure 1, gave a rating of 1 or 2 for both aesthetics and transparency, namely they did not like and did not understand the graph. Noemi, conversely, gave a rating of 4 to aesthetics and to 3 to transparency, because, in her words, "I understand the general meaning, but I don't understand the numbers on the y-axis" . Also in Noemi's case, a formalist-oriented view emerges, she focuses on the readability of the y-axis.

The participants who interpreted the Factfulness bar graph incorrectly represent a percentage of about 10% of the entire sample and Table 1 summarises our analysis so far.

Table 1. Summary of the selected excerpts of students' accounts for why they found the graph transparent/beautiful; these students gave an incorrect interpretation of the graph in Figure 1, namely the one on oil tanker spills.

Student name	**Student's interpretation**	**Rating: aesthetics**	**Rating: transparency**	**Mathematical view**
Francesco	One does not immediately get the information from the graph	5	2	formal-oriented
Arianna	It's all glued together, but I think the choice of the bar graph is right because it allows you to see the differences better.	3	1	formal-oriented
Noemi	I understand the general meaning, but I don't understand the numbers on the y-axis	4	3	formal-oriented

19 respondents did not answer the question, while another 14 participants simply noted the decrease in the number of tanker spills, a correct, but very brief, response. Slightly more than a half of the respondents gave a correct and articulated answer to the question, and Table 2 reports some examples of these interpretations

Table 2. The table reports examples of students' correct interpretations of the graph in Figure 1, namely the one on oil tanker spills..

Student name	Student's interpretation	Rating: aesthetics	Rating: transparency
Franca	Yes, there was growth until 1975, when the peak was recorded, and then a gradual decline was observed until 2018. In general, there was an alternation of increases and decreases, but overall there has been a peak and a consequent decrease.	3	3
Gianni	Since 1970 there was an increase, until about 1974 and then a slow decrease in accidents related to oil spills from tankers despite the large increase in trade.	5	3
Anna	In this graph one can see how oil spills have significantly decreased despite the fact that oil transport has significantly increased, especially from 1976 to 2018. The peak of tanker spills occurred in 1976, with about 3000, and then it went on decreasing more or less gradually until 2018, while oil transport had a negative peak in 1985 and started to grow again until 2018.	5	4

From Franca's, Gianni's and Anna's responses in Table 2 we can notice that these students, as well as over half of the respondents, could correctly read the graph in Figure 1 and were able to articulate their interpretations in good detail. Interpreting this result under the lens of the Factfulness project, we can confirm that showing a graph of that sort allows people to recognise the facts about tanker spills and correct any potential misconceptions. We also noticed that those who gave an incorrect interpretation to the graph, focused mostly on the line graph, and we hypothesise that this can be due to the difficulty, highlighted by Garfield and Ben-Zvi (2007), in considering the distribution of data. Bar graphs often convey information about frequency distribution and hence a difficulty in reading a bar graph can be traced back to a difficulty with distribution even when a bar graph is used to convey information about a time series, as it is the case in the graph under analysis.

4.2 Aesthetics and mathematical views for a graph on oil tanker spills

We also looked to the participants' accounts for why they found the graph in Figure 1 aesthetically pleasing (or not), and we coded them according to the four mathematical world views by Erens and Eichler (2019), and we found that 22% of student responses focus on the clarity of the graph, thus they can be coded as belonging to the formalist-oriented view. Examples of students' accounts that have been interpreted as referring to clarity are reported in Table 3.

Table 3. The table reports examples of students' accounts for aesthetics of the graph of oil tanker spills.

Rating: aesthetics	Student's interpretation	Mathematical view
2	Too much information and it's unclear, poor colour contrast and writing is too small.	formal-oriented
3	The colour distinction for the two graphs, with the respective values on the left for one and on the right for the other, allows for clear reading. The problem, in my opinion, lies in the use of two different types of graphs, which can easily lead to confusion.	formal-oriented
2	The graph is unclear as there is too much data inserted inside, a legend is missing.	formal-oriented
4	I find it completely clear, except for the English text which contains some "technical terms"	formal-oriented

9% of the answers mention order, and another 2% of the answers refer to both order and clarity. Examples of answers of this sort are: "too much information and not very clear, poor colour contrast and writing too small" or, "I understood well what the graph wants to represent and it is tidy". Another example was, "everything in this graph seems to be placed randomly, without any clear order or meaning". As we can notice, these accounts focus on how clear the graph is and mention also tidiness in some cases. Order refers to the formalist-oriented view hence we can say that 33% of the accounts for why participants found the graph in Figure 1 (more or less) beautiful are coded as formalist-oriented.

Another 5% of the answers can be coded as belonging to the application-oriented view and an example is: "it uses two types of graphs to highlight the information". For this account, we notice that the focus is on the real data that is shown by the graph itself. Another example is, "I think this is the right graph for collecting data for this type of research, but it is missing a legend that explains the solid fuchsia line". This student connects the choice of the type of graph with the kind of data one has to deal with, and they stress the importance of having a legend for interpreting the information conveyed.

4% of the answers were coded as a schema-oriented view, and they refer to how easy it is to read the graph. An example is, "I don't understand the data I need to find". This student refers to the procedure, to the data needed and to their difficulty in finding them easily.

26% of the accounts do not mention anything but the colours (as it is the case of Francesco, our first example), or comments on how they liked it, for example, "I don't find the difference between the bars and the red line pleasant", or "two colours are used that go well together", and we cannot assign a view to this kind of answers. In this case it is not possible to code the answers according to any mathematical view. 2% of the respondents refer to the kind of diagram, saying that they "like this kind of graph", for example. In this case, it is also not possible to assign a mathematical view. 29% of the respondents did not give any account and just left the answer blank.

Many student responses relating to aesthetics reveal a formalist view of mathematics, and in particular focus on clarity and/or order. Therefore, we can conclude that for many students, mathematical beauty equates to order and cleanliness. The few responses that connect mathematical beauty and application focus on the information that graphs convey, about the real data.

4.3 Transparency and mathematical views for a graph on oil tanker spills

We dwell on the accounts for why the students found the graph in Figure 1 (not) transparent and we code them according to the mathematical views that emerge, whenever possible (28% of the participants gave no response). We report that 49% of the students' comments about the transparency of the graph were coded as a formalist-oriented view, since they referred to lack of clarity and/or order. We show some examples in Table 4. Another 12% of the accounts can be coded as eliciting an application-oriented view, since they do not focus on the mathematical properties of the graph, rather they refer to the real world, to the data that the statistical graph shows. Some examples are reported in Table 4, as well.

Finally, 9% of the students' accounts can be coded as a schema-oriented view, as they refer to easiness of reading the graph, or adherence to certain graphs they know from school, and one student's account can be coded as a process-oriented view, as it refers to the reasoning process that is required in order to interpret the graph.

Table 4. The table reports examples of students' accounts for transparency of the graph about oil tanker spills.

Rating: transparency	**Student's interpretation**	**Mathematical view**
1	The lack of a legend makes it less clear	formal-oriented
3	The division of the two colours relating to the two categories is clear	formal-oriented
1	It seems that everything in this graph is placed randomly, without any specific order or meaning	formal-oriented
2	The red and blue numbers on the side do not have a grid that makes it easier to understand how to connect the numerical data to the year.	application-oriented
4	I argue that the graph shows the growth/decrease trend of the data in an optimal way, but at the same time it does not give me the possibility to evaluate the growth percentages with great precision	application-oriented
3	In my opinion, the presentation of the graph alone, without the reference data, is not very clear.	application-oriented

3	The graph is clear, however the red line is a bit confusing, as it suggests an increase in oil loss during the years.	application-oriented

In summary, our findings about how participants approached the bar graph on tanker spills show that a reasonable proportion of students were able to interpret it correctly, but others were unable to grasp the information depicted in the graph. Overall, the graph has been seen as somehow aesthetically pleasing and transparent by the majority of the participants, and a formalist-oriented view of mathematics seems to prevail when the participants have to justify why they find the graph beautiful (or not) and transparent (or not). With respect to transparency, we also noted that an application-oriented view of mathematics emerged.

4.4 Interpretations of a graph on marine protected areas

To recall, the graph shown in Figure 2 is a line graph showing the trend of marine protected areas in recent years. Since we asked the participants to write the information they got from the graph, we are able to report that only one student said he did not know how to interpret it (Pietro, with an aesthetics rating of 1, and a transparency rating of 2). 19% of the respondents did not give an answer, 28% of them wrote that they notice that the area has increased (with no reference to any number or quantity), and more than one half of the respondents gave a detailed answer. Examples of answers of this sort are shown in Table 5.

Table 5. The table reports examples of students' correct interpretations of the graph in Figure 2, namely the one on marine protected areas.

Student name	**Student's interpretation**	**Rating: aesthetics**	**Rating: transparency**
Nour	ABJN has remained the same for a long time and started to increase in 2016, however, at the national and global levels, marine protected areas have increased much more. Global ones have surpassed national ones around 2016.	4	4
Giorgia	The graph shows the years on the x-axis and the surface area in square kilometres on the y-axis. Looking at it, we note that compared to 2016, the surface area occupied by marine protected areas has increased rapidly at a national and global level, noting a very similar rapid increase, although at a global level the increase is higher. Even at the ABNJ level, we note a slight increase from 2016, which however remains constant over the years.	4	5
Virginia	The area occupied worldwide (Global line) by marine protected areas has increased from approximately 15,000,000	3	5

	square kilometres to approximately 30,000,000 square kilometres.		
Barbara	In the graph we can see that compared to 2016 the surface area occupied by marine protected areas has increased especially in the "national" and "global" bands. There was also a clear peak for the "ABNJ" data.	3	2
Emanuele	It increased exponentially in the first 2 years, then since 2018 it has remained practically the same surface area.	2	2

From Table 5, it seems that the quality of the interpretation of the graph is somehow irrespective of the ratings given to aesthetics and transparency. The participants understand that the correct answer to the question about the trend of marine protected areas since 2016 is that it has increased and they are able to successfully describe the information they got from the graph .

4.5 Aesthetics and mathematical views for a graph on marine protected areas

If we dwell on the accounts that the participants gave for their ratings about the graph's aesthetics, we notice that 48% of the responses fall into a formalist-oriented view. Examples of answers of this sort are reported in Table 6.

Table 6. The table reports examples of students' accounts for aesthetics of the graph on marine protected areas.

Rating: aesthetics	**Student's interpretation**	**Mathematical view**
3	The dots are too big but the colours are nice.	formal-oriented
3	I would have preferred them to specify what the acronyms mean (in particular ABNJ), furthermore I can't understand on what basis a dot is whole, half, bigger or smaller (they are not well aligned at the final graphic level).	formal-oriented
4	Colours allow the eye to focus attention on the graph and these allow us to distinguish the different trends well.	formal-oriented
5	Aesthetically I find it very nice because I find the colours used to differentiate the data clear, different shades and this allows one to read the graph well, even the type of graph is clear for me, one can easily visualize a growth over time.	formal-oriented

4.6 Transparency and mathematical views for a graph on marine protected areas

With respect to transparency, we consider the accounts for the ratings given and we dwell on a selection of them. 66% of the open answers can be considered within the formal-oriented view, and they are very similar to the ones reported for the aesthetics, but another 6% of the answers focus on the application-oriented view and are reported in Table 7.

In these cases, we notice that the focus is not on clarity per se, but a reference to the data that the graph reports is at the center of the participants' account. This is typical of an application-oriented view.

Table 7. The table reports examples of students' accounts for transparency of the graph on marine protected areas.

Rating: transparency	Student's interpretation	Mathematical view
3	I would have preferred a little more contextualization and explanation or translation of the parameters found below.	application-oriented
5	It allows the change in the surface to be made visible.	application-oriented
5	It is easy to give an estimate of the numbers over the years.	application-oriented
3	The data is easy to highlight.	application-oriented
4	I argue that the graph shows the growth/decrease trend of the data in an optimal way, but at the same time it does not give me the possibility to evaluate the growth percentages with maximum precision.	application-oriented

5 Discussion

The mathematical views lens developed by Erens and Eichler (2019) has helped us to outline that in most cases a formalist-oriented view of mathematics, pivoting around tidiness, order, and clarity, emerges as a criterion. Regarding transparency, while the formalist view remained dominant, a notable number of responses also reflected a schema-oriented perspective, emphasising familiarity with the type of graph and ease of reading; this highlights how familiarity with school-taught procedures and representations plays a role in graph readability. An application-oriented view also emerged, particularly when participants referred to the graph's capacity to reveal meaningful trends or real-world implications. These findings underscore that students' beliefs about mathematics shape not only how they understand a graph, but how they feel about it, in terms of its beauty, clarity, and usefulness.

This research fits in with Coles et al's (2013) approach to the challenge of teaching mathematics as if we cared about the planet. In our study, misconceptions that have been highlighted in the literature emerge in students' writing. However, these graphs (which do not have a mathematical value in themselves, but rather prompt reflection on environmental facts) shift the majority of students' attention toward a correct interpretation. The emergence of a formal-oriented view could support this shift, as it parallels a shift from a schema-oriented view promoted in high school to a more advanced one, overcoming the beliefs overhang (Daskalogianni & Simpson, 2001). Furthermore, we can observe that the Factfulness project focuses on multiple-choice answers, while our study, while not discounting the percentage of answers provided, focuses on what happens when the graph with the correct information is shown. Similarly, we collected quantitative data in relation to students' perceptions of aesthetics and transparency (on a scale of 1 to 5), but our primary focus was on how graphs are experienced and lived by students, and therefore how they describe them.

We can therefore attempt to answer the research question about the process that leads people to make decisions based on their perceptions of aesthetics and transparency, interpreting these from a framework of mathematical views, conceptions and beliefs. In order to understand a statistical graph, people need it to be clear, tidy, orderly. These features make the graph also beautiful. In other cases, transparency of a graph is perceived when it allows readers to see the link with the real data and to tackle the issue coming from the real world, under analysis. All in all, statistical graphs seem to promote a shift from a schema-oriented view of mathematics, which is typical of high school, to a formal- or an application-oriented view, which in turn can promote well-informed believes about mathematics.

6 Conclusions

The findings of this study contribute to shedding light on the complex interplay between individual mathematical views, the perceived aesthetics and transparency of graphs, and the capacity to correctly interpret data. When asked to explain why they found a graph aesthetically pleasing or transparent, participants frequently mobilised a formalist-oriented view of mathematics, characterised by references to clarity, order, and precision. This suggests that aesthetic appreciation, in this context, is not merely a matter of visual preference, but rather rooted in epistemological beliefs about what makes a mathematical object "well-formed" or "correct". The idea that beauty is linked to order resonates with historical perspectives in both mathematics and philosophy, as it is also noted by Sinclair (2009).

These results suggest that students' interpretations of graphs are filtered through their mathematical beliefs, which act as cognitive lenses affecting both comprehension and judgment. A tentative conclusion that we can draw is that a graph's perceived clarity and beauty are not purely aesthetic or perceptual, but their perception can be shaped by a complex mix of familiarity, conceptual understanding, and affective response.

This observation becomes particularly relevant in relation to the Factfulness project's aim, that is, to correct widespread misconceptions about global phenomena through the use of statistical graphs. The findings highlighted by the Factfulness project show that misconceptions can persist at any educational or social level, and this is confirmed by our study, from the number of participants who misinterpreted even well-designed graphs. The examples of Francesco and Arianna suggest that, when participants fail to correctly interpret a graph, they probably tend to rely on their own personal beliefs to make sense of it. We can also notice that, in both cases, the students either misread or misunderstood the data but still felt the need to offer an evaluative response that was often grounded in their perceptions of clarity or familiarity, rather than a true interpretation of the represented phenomenon. This supports the idea that in the absence of comprehension, belief systems fill the interpretive gap, potentially reinforcing rather than challenging misconceptions. We can hypothesise that graphs can effectively "cut through" individual belief systems, offering an accessible pathway to factual understanding. Even when students hold certain beliefs, the presence of a clear and aesthetically compelling graph can enable them to reach more accurate interpretations.

In this sense, graphs act not only as tools for data representation, but they hold a potential of becoming instruments for conceptual transformation. Their capacity to communicate data effectively, especially when designed with visual clarity and aesthetic coherence, makes them powerful vehicles for promoting awareness and challenging entrenched misconceptions. The participants' comments reveal that a graph is considered beautiful not just when it looks appealing, but when it does its job, that is, when it communicates data in a way that feels accessible, trustworthy, and informative.

In our study, we encountered exceptions to this generalisation. Some students made mistakes. Therefore, there are limitations to the conclusions we can draw. Studies in mathematics education (e.g., Roth, 2003) suggest that students should learn to construct their own graphs to become proficient in interpreting the graphs produced by others. This is certainly an avenue worth exploring in future research on this topic.

Research ethics

Author contributions

A.A.: conceptualization, methodology, validation, visualization, writing — reviewing and editing.
C.A.: investigation, formal analysis, writing — original draft preparation.
L.D.: data curation, writing — reviewing and editing.

All authors have read and agreed to the published version of the manuscript.

Artificial intelligence

No AI has been used for this study. Being the authors not-native in English, some paragraphs have been written in Italian first, then translated into English with the aid of Google translator or Reverso.

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Informed consent statement

Informed consent was obtained from all research participants.

Data availability statement

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Conflicts of Interest

The authors declare no conflicts of interest.

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