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An exploratory study of teachers' ideas about the shape of the earth and the transition of students' ideas from the flat earth to the earth globe[+*]

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Abstract

This work analyzes the answers presented by researchers and teachers in pre- and in-service teacher education to a questionnaire about the shape of the Earth including certain physical implications of its form, as well as issues related to the teaching and learning of this topic. Furthermore, we tried to understand how teachers dealt with the ideas of the flat Earth denialist movement. The questionnaire was answered at academic events, research groups in the area and in Astronomy education classes. In total, 66 subjects responded to the questionnaire. The analysis showed an adequate level of respondents in relation to knowledge of the shape of the Earth. However, there is a lack of recognition regarding some astronomical implications of the Earth's roundness, such as the percentage of flattening of the poles. We also realize that in problem

[+] Um estudo das ideias de professores acerca da forma da terra e sobre a transição das ideias dos estudantes desde a terra plana ao globo terrestre

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situations with examples involving distances and physical dilemmas, there is some difficulty with the relative size of the Earth and its surroundings. In this way, the questionnaire presents itself as a tool that allows us to encourage these discussions, taking us to pedagogical and epistemological spheres of the issue of teaching and learning about the shape of the Earth.

Keywords: *Shape of the Earth; Astronomy Education; Learning.*

I. Introduction

The recent rise of science denialism has challenged educators in general, especially those who teach subjects that encompass scientific knowledge questioned by this movement, such as the evolution of species, the use of vaccines, and, in the case studied here, the shape of the Earth.

This latter context of denialism proves to be very challenging since the BNCC (2017) introduced a few years ago an extensive list of astronomy topics to be addressed in the early years of Elementary School, the understanding of which directly involves the notion of a spherical Earth or depends on this notion for other topics to be understood. The challenge increases as teachers qualified for this level of education rarely demonstrate consistent conceptual mastery to provide an adequate and effective approach, as evidenced by Langhi and Nardi (2005), Ferreira and Leite (2015), and Silva and Langhi (2021).

Even before the rise of denialist movements and the new BNCC guidelines, we have been investigating didactically more complex (Harres, 2000) and epistemologically less absolutist (Toulmin, 1977) ways to address the issue of the shape of the Earth in basic and high education, within the broader context of astronomy education (Harres; Rocha; Henz, 2001; Bartelmebs; Harres; Silva, 2014; Bartelmebs; Harres, 2014, 2017; Bartelmebs *et al*., 2016; Bartelmebs; Figueira; Diel, 2023; Bartelmebs *et al*., 2023). We believe this new denialist context further reinforces the need for us to advance as educators and researchers in both didactic and epistemological terms.

In recent years, when invited to speak about the didactic approaches to the shape of the Earth at science education events and research meetings, which include astronomy education, we have developed and refined a PowerPoint (PPT) presentation. To offer our opinion and stimulate discussion on this topic, the PPT is titled “In Defense of Flat Earthers: The Complexity of Teaching and Learning About the Shape of the Earth.”

As the title suggests, we promote reflections that mainly seek to overcome the simplistic view that we must “combat” Flat Earth ideologies by presenting irrefutable evidence of the Earth’s sphericity and the “true” explanations of certain phenomena that “prove” the round shape of our planet, nearly an imposition of the spherical notion of the Earth. One example among many would be explaining why pilots flying over the Earth's surface do not need to constantly "lower the nose" of the plane to continue flying over the surface.

Beyond the exhaustive and consistent work already produced in this line of research, such as Silveira (2017) and Azevedo *et al.* (2022), our questioning focuses on epistemological absolutism, whether of an empiricist or rationalist nature (Porlán; Harres, 2002), or an empiricist conception of learning (Harres; Bartelmebs, 2017), often implicit in these explanations. For example, arguments such as "the truth (spherical Earth) is unequivocal", "the idea of a flat Earth is absurd", "the ancients already knew that the Earth is round", and "one just needs to 'better' think about or observe it to be convinced" are frequently used in this type of discussion.

Throughout the presentation, we show a series of data and information about how our planet has been perceived over time, how its size and relief are compared, and the flattening at the poles, as well as a deeper understanding of how gravity varies and acts both on and within the Earth. From a didactic perspective, we present research results on how children perceive the Earth's shape and gravitational action. The connection with adult understanding is illustrated through the historical evolution of conceptions about our planet.

Completing the PPT, we discuss the didactic dimension of the topic by analyzing how teachers perceive these perceptions (worth the redundancy) and how they consider and address them in class. To do this, we rely on Hashweh's (1996) guidelines and our results (Harres; Rocha; Henz, 2001; Bartelmebs; Figueira; Diel, 2023). More recently, this presentation evolved into a textual and illustrated record and was published in Harres and Peixoto (2023), which, due to space, allowed for a deeper analysis of the historical, geographical, physical, and pedagogical aspects of this topic.

And as, in recent years, this presentation has been repeated, we have sought to make our practice more consistent with our discourse, to be less transmissive and more interactive, complying with the importance of identifying and considering students' ideas (our audiences, in this case). Thus, we began to apply an online questionnaire to the audience before the lecture, to identify their initial positions, their knowledge about the data and information to be presented, and their starting didactic perceptions. Using Google Forms, it was possible to present and discuss the audience's responses to the questionnaire in contrast with our information.

Therefore, this work analyzes the responses to the questionnaire included in the Appendix to this article, composed of responses collected in three editions of this activity conducted between 2021 and 2022, in which teachers working at higher and secondary education levels participated.

II. Theoretical Foundation

It is necessary to consider three main ideas as fundamental to our analysis. The first refers to some aspects of how learning a new idea occurs, especially when it conflicts with an already established everyday way of thinking. The second idea has an epistemological character, as it analyzes the status of the flat and spherical Earth concepts within the context of defining school knowledge. Finally, considering the two previous ideas, we explain how we conceive the teaching of the Earth's shape and which formative implications derive from it.

Regarding the first principle, we start from a viewpoint in which learning is always a process that, in some way, relates to what the individual already thinks—in other words, the student's ideas. Thus, the learning of a new idea or concept, especially when it confronts a preexisting belief, is not the result of filling a "blank" mind or a mere replacement of incorrect knowledge with correct knowledge (Petrosino, 2000; Bartelmebs; Harres, 2017; Bartelmebs *et al*., 2023).

Pioneeringly, the studies of Piaget (1926) and his collaborators from the Geneva School presented children's logic as different from that of adult subjects. From these works, many researchers delved into the world of children to understand their conceptions of the world. The pedagogical translations of Piaget's ideas were only partially realized in constructivist approaches to teaching, particularly in science education based on the discovery learning methodology. In Brazil, science education gained greater prominence in the Basic Education curriculum starting in the 1960s, as stated by Krasilchik (2000, p. 88):

> *During the period 1950-70, the prevailing idea was of the existence of a fixed and basic sequence of behaviors that would characterize the scientific method in identifying problems, formulating hypotheses, and experimentally verifying these hypotheses, which allowed for reaching a conclusion and raising new questions.*

According to the author, no matter how detailed the books or proposed activities were, the results were not up to par. In search of the reasons behind this failure, it was "discovered" that children have ideas about the world that interfere with their learning of scientific concepts. Cubero (1994) states: "Many of the so-called children's representations, obtained through interviews or questionnaires, may be nothing more than methodological artifacts constructed from the very systems of exploration and recording" (p. 34).

In this context, it is worth highlighting that we conducted an extensive review on the subject (Bartelmebs; Harres, 2017). This review shows that these ideas reflect the logic of children and adolescent reasoning, which often does not follow the same structure as school knowledge. The breadth of research on the topic devised in the last century allowed for the creation of catalogs documenting what children think about different topics at different ages, as exemplified by the work of Driver, Guesne, and Tiberghien (1999).

In the context of research on how children perceive the Earth in terms of its shape and gravitational action, the work that stands out the most is that of Nussbaum (1979). Through clinical interviews with children of different ages and highly creative practical situations, he identified three ideas that structure the evolution of this concept from a flat Earth notion to a spherical understanding of our planet. This evolution would be gradual, generally passing through three intermediate stages that depend on how the notion of shape (flat or spherical), the surrounding space (all around it or just above), and the way gravity acts (toward the surface or the center of the Earth) are situated. The author found that these five levels are quite prevalent among groups of children of different ages. In particular, Nussbaum (1979) observed that only half of the children aged 14 to 15 could be associated with the highest level. In Brazil, Nardi and Carvalho (1996) found the same results, reinforcing Nussbaum's perspective and demonstrating its applicability to different contexts as well.

Before advancing to the didactic principles that guide our thoughts on teaching about the shape of the Earth, it is important to consider how the historical evolution of the conception of the Earth's shape relates to a school knowledge view. This knowledge, in our opinion, should be defined beyond the mere overcoming or elimination of everyday knowledge and, at the same time, beyond imposition, often implemented through assessment practices, of the dominant scientific conception.

From this perspective, even if we admit that the flat Earth view in earlier periods may not have been widely disseminated, it is undeniable that, at the very least, its representation in various works proved challenging in aligning with everyday phenomena. An example is the integration of the Earth's spherical shape with Aristotle's theory of the four elements (Harres; Bartelmebs, 2023, p. 48). Thus, considering the findings of Saltiel and Viennot (1985), the theories of Piaget and Garcia (2011), and what we have also identified (Bartelmebs, 2014), it seems quite plausible to establish a connection between children's understandings and the historical evolution of our planet.

Accepting this parallelism between children's ideas and scientific thought, we can analyze how to overcome the simplistic dichotomy between the flat or round Earth notion. First, it is necessary to consider that there is a significant distinction between the size of things and phenomena we deal with daily and the size of astronomical phenomena, such as the size of the Earth. Even though the flattening at the poles is more than twice the height of the highest point on Earth's surface, this value is negligible compared to the Earth's radius. Therefore, in any photograph of our planet taken from a distance where it can be seen in its entirety, we cannot perceive this flattening that leads to the difference in its radius at the poles and the Equator.

Thus, there are many everyday phenomena, and even those involving precision measurements, where it is more useful to consider the Earth as flat. For example, when masons use a plumb line to verify the verticality of two nearby walls, they consider the vertical direction of the lines as parallel and, therefore, the space involved is flat. At the same time, in positional astronomy, the location of stars and other celestial bodies relative to an observer's position on the ground is determined by measuring the angle of sight with the surface, assuming a flat horizon.

Similarly, Lanciano (1989), in the context of the discussion between geocentric and heliocentric models, argues that there is no practical reason to disregard the Ptolemaic model in describing the movements of celestial bodies. This does not imply disregarding the broader description to situate our place in space, as proposed by the Copernican model, which has its cultural value and utility, for example, for our travels to the Moon or another planet. According to this author,

> *(...) there are some paths in the history of science and culture, as well as in individual knowledge processes, that can lead to the use of both models, the Ptolemaic and Copernican models, without having to choose between one or the other to refer to the same reality"* (Lanciano, 1989, p. 173).

Finally, we arrive at the third guiding principle of our reflections, which emerges as a pedagogical implication of the previous two by indicating what to do didactically with students' ideas. Here, it is worth considering what Petrosino (2000) states; according to him, if we tell a child that they are wrong to think the Earth is flat and force them to think like us, they will not understand what we have told them and will not know how to use this knowledge. In the end, the child now knows less. Worse still, by feeling distrustful of their reasoning, they will be discouraged from thinking for themselves about everyday problems. In short, according to this author, "a bad model is better than no model" (p. 52).

This relativistic view of both everyday knowledge and official (scientific) knowledge aligns with what Hashweh (1996) proposes when analyzing the potential of didactic strategies to promote students' conceptual evolution. According to this author, strategies such as explaining and convincing (by presenting evidence of the Earth's round shape, for example) would have limited potential. At the highest level of potential, he places those strategies that start from what students think, and propose the development, as autonomously as possible, of students' ideas, seeking a restructuring that overcomes the simplistic dichotomy between a flat and round Earth. The proposal by Gangui (2014), which suggests fixing a card representing a flat horizon onto a school globe, is an interesting example that moves in this direction.

In our previous studies (Harres; Rocha; Henz, 2001; Bartelmebs; Figueira; Diel, 2023), applying the dilemma proposed by Hashweh (1996), this level of strategy with the highest potential to promote conceptual evolution hardly appeared among the teachers or future teachers involved. Even when it was proposed to start from students' ideas, the final goal, whether implicit or not, was to replace the initial idea, which aligns with the level defined by Hashweh (1996) as "refutation", characterized by the intention to show the student that they are wrong and then present the correct knowledge.

In conclusion, beyond the didactic and epistemological dimensions, this restructuring also has curricular implications. Indeed, it aligns with what García (1998) advocates regarding the desirable definition of school knowledge. According to this author, the knowledge constituting the curriculum should be organized in such a way as to seek a transition from simplistic thinking toward a more complex understanding of reality, rather than a transition (or replacement) from everyday knowledge to scientific knowledge. In the case of the Earth's shape, the curricular objective, according to this author's proposal, would not be solely or primarily the shift from a flat to a round conception, but rather the understanding that the Earth's shape can, depending on the context, be conceived in different ways. For example, in the context of a mason using a plumb line to build parallel vertical walls, the flat conception of the Earth's shape is implicitly assumed. If he were to consider the “true” round shape of the Earth, his work would be significantly hindered. On the other hand, the flattening of the Earth’s poles, a result of non-negligible mechanical factors of its rotation, is not noticeable in photographs taken from a great distance due to its insignificant value compared to Earth’s radius.

Thus, we consider that the scope of this complex perspective through which the Earth’s shape can be conceived – that is, dependent on the context of analysis – would go beyond mere informative learning and would ideally align with the highest level proposed by Hashweh (1996) regarding the potential of didactic strategies for conceptual evolution. We take this scope as a desirable reference in analyzing the didactic options presented to the subjects investigated when responding to the questionnaire.

III. Method

This study analyzes the online application of a questionnaire with ten questions, shown in full in the appendix, related to discussions about the shape of the Earth. The questionnaire included, on this topic, questions about (a) the flat Earth versus round Earth controversy, (b) the non-trivial physical implications of the Earth being round, and (c) the consideration and didactic treatment of conceptions commonly presented by Basic Education students in class regarding the shape of the Earth.

The version of the questionnaire analyzed here underwent some revisions based on previous applications. It was answered by 66 subjects across three events held between 2020 and 2021, involving higher and secondary education teachers.

The collected data were analyzed as a single sample, without differentiating the type of event, level of education, or other profile characteristics such as the State of origin of each respondent (subjects from all regions of Brazil participated). Since some questions were not included in certain applications of the questionnaire due to time constraints for the activity, not all subjects answered all 10 questions. Therefore, some analyses involve fewer responses. Individual data, such as level of education or teaching experience, which could be related to different responses to the questionnaire, were not collected. Nonetheless, Langhi (2011), in a comprehensive research survey on alternative conceptions in Astronomy, concludes that these are frequently present in different contexts and educational levels.

The questionnaire contained three types of questions: (a) single-choice questions with alternatives presented on a gradient of correctness; (b) opinion-based single-choice questions; and (c) multiple-choice questions with alternatives presented on a gradient of appropriateness according to the adopted framework. Table 1 shows the theme and type of each of the ten questions.

Table 1 – Theme and type of questions in the questionnaire.

Nº	Subject	Type	Nº	Subject	Type
1	Shape of the Earth	Single-choice	6	Tunnels crossing the Earth	Single-choice
2	Reasons for denialism	Opinion-based	7	Eratosthenes' experiment	Opinion-based
3	Flattening of the poles	Single-choice	8	Flat Earth myth in the Middle Ages	Opinion-based
4	Relief on a school globe	Single-choice	9	Reason for believing that the Earth is flat	Single-choice
5	Seaside horizon	Single-choice	10	Strategies for conceptual evolution	Multiple-choice

The analyses conducted were quantitative. A score evaluating the degree of correctness or appropriateness of the responses for each subject to the non-opinion-based questions was not constructed. This was because, after parameterization and calculating Cronbach's Alpha reliability coefficient (1951), we found a non-significant value (0.11). This low value indicates the presence of diverse individual perspectives when responding to the questions. Even the same person might have answered one question or a group of questions according to one framework and other questions using a different one. Nevertheless, it is worth noting that, where applicable, the most appropriate responses based on our theoretical framework would have an average adequacy percentage of 30%, with a standard deviation of 20%.

In the following sections, the analyses of the responses obtained for each question are detailed, considering the related content, while discussing the desirable teaching and learning perspectives that can be derived from them, where possible, according to a gradient of appropriateness relative to the adopted framework.

III.1 Analysis of Question 1 (n=40)

The first question asked briefly and objectively what the shape of the Earth is. Of a total of 40 responses, 37 (approximately 95%) of respondents marked "oblate geoid" and three subjects (5%) responded that it is spherical. Nobody chose the flat shape. The high marking in the "oblate geoid" option points to a strong presence of the notion that the Earth is flattened at the poles and/or the supposedly more precise academic language.

However, extensively and thoroughly analyzing the shape of our planet, Silveira (2017) indicates that the most appropriate way to represent it consists of a normal sphere, essentially almost perfect. The flattening, the mapping of gravity on the surface, the ellipsoid shape, and the differences in relief essentially present minute differences. Its mention would result from detailed analyses of different perspectives on our planet, which are nonetheless important. Cruz (2018) also analyzes these "different" forms of the Earth, arguing how challenging it is to try to define "the" shape of the Earth. This difficulty, in its epistemological and didactic dimension, meets the framework of this work.

III.2 Analysis of Question 2 (n=37)

The second question referred to the denialist movement advocating the idea that the Earth is flat. Respondents were asked for their opinion on the main reason why this notion is so widespread today. According to recent data from the Data Folha survey, in Brazil, young people aged 16 to 24 and elderly people over 60 are the groups that most support the flat Earth idea. This group may reach over 11 million people, according to a 2021 study. However, the objective of this and other questions is not to discuss the denialist movement but to analyze how the topic of the Earth's shape is (or is not) addressed in schools, potentially influencing (or not) this movement.

Of the responses obtained, 85% answered as requested, selecting only one option, while 15% selected more than one option. Those who selected only one option were evenly distributed among three choices: (a) It aligns with our everyday experience; (d) Lack of consideration and discussion of alternative ways of interpreting reality in school learning; and (f) Psychological attraction to thinking differently from others, to believing that no one knows something else does, that there is a group manipulating us, etc. Considering those who selected more than one option and tallying the total responses received for each option, the dispersion increases, but the balance remains, covering 70% of the indications. However, in this case, the most selected option becomes (a).

III.3 Analysis of Question 3 (flattening of the Earth), Question 4 (flattening on the school globe), and Question 5 (distance to the horizon at sea level) (n = 66).

In questions 3, 4, and 5, the percentage of correct answers was 20%, 35%, and 25%, respectively. No subject answered all three correctly, ten answered two questions correctly, and half of the group answered only one. More than one-third (35%) did not answer any correctly. Another general comment regarding these three questions is that, among the responses provided by the subjects, the correlation index of each with the other two was practically zero. In other words, the way of answering any one of them is not related to the way of answering the other two.

In Question 3, the most accurate answer is 0.33% of flattening. Since the questionnaire was interested in evaluating the order of magnitude of the percentage flattening estimated by the respondents and not whether they knew a more exact value by heart, the best answer is 0.1%, chosen by 20% of the subjects. After this option, the value of 1% is the closest, chosen by 15% of the subjects. Those who assumed a much smaller flattening, 0.01% or 0.001%, accounted for 55% of the total, and one-tenth of the total subjects indicated a pronounced flattening of 10%.

Question 4 asks how the representation of Mount Everest, the largest geographical "accident" on Earth, would be on a school globe, considering the size (radius) with which these globes are generally constructed. Here, the group that answered most accurately (assuming an order of magnitude in millimeters) achieved the highest percentage of correct answers among the three questions currently under analysis: 35%. However, only 10% of the sample answered this and the previous question correctly.

After the correct option, the most selected in this question (30%) was the one corresponding to micrometric flattening. Of these, half were consistent with the answer given in the previous question, having marked options (a) or (b), that is, very slight flattening. However, this consistency was not the trend for the general group. By parameterizing the options of each of these questions, since they are presented in ascending numerical order, that is, assigning values 1, 2, 3, and so on for each of the options in each question, a very low correlation index is found (r = 0.09), which means that, in general, those who indicated a proportionally large flattening for the Earth also estimated its representation on a school globe to be smaller than those who marked the very small proportional flattening and vice versa.

Several reasons can be pointed out here, such as that thinking in three dimensions is difficult, world maps are used more (especially in history and geography classes) than globes, etc. In any case, it seems that the school globe is explored little regarding its three-dimensional representation.

Concluding this subsection, the answers to Question 5 showed a picture like the previous two, with an accurate rate close to one-third (25%), with a large distribution among the options. The question aims to evaluate how subjects estimate how Earth's sphericity affects the view of ships moving away into the sea, without initial concern for the exact value, which is very close to 10 km. The percentage of correct answers was 25%. Of the others, almost half estimated that the curvature of the Earth observed on the horizon would be little pronounced: 25% marked 30 km, 20% marked 60 km, and 5% marked 100 km as the distance for the ship to disappear. Those who assumed a well-pronounced curvature, one or three kilometers, totaled 25%.

Just like in the joint analysis of questions 3 and 4, again few got Question 5 right and any of the previous ones: three subjects answered questions 3 and 5 correctly while five answered questions 4 and 5 correctly. Calculating the correlation of Question 5 with the two previous questions by parameterizing the options presented in the same way, a practically negligible value (0.12) was found with Question 4; however, the correlation with Question 3 was high (0.71). In other words, those who indicated a very small flattening of the Earth tended to mark that the ship disappears on the horizon at a much shorter distance compared to those who assumed a proportionally greater flattening of our planet.

III.4 Analysis of Question 6 (n = 31)

Unlike the previous three questions, Question 6 is certainly the most difficult from the perspective of the physical understanding involved. Understanding fictitious movements of objects within the Earth through tunnels that cross it from one distant point to another, that is, much longer and deeper than those that cross mountains, does not seem trivial.

This situation is explored in a very interesting way by Perelman (1970). Nussbaum (1979) also used the idea of objects falling through tunnels that cut through the Earth to differentiate the last two levels of conception about the shape of the Earth from the five he constructs based on interviews with children and adolescents. As he showed, a student may accept that the Earth is round, and that the sky is all around it, but have difficulty understanding that the fall of bodies occurs, essentially, towards the center of our planet and not towards the surface. The correct answer to the question also involves understanding that as we approach the center of the Earth, the force of gravity decreases, being null at its center.

More than evaluating the understanding of the physical concepts involved, such as understanding how the force of gravity varies within the Earth as we approach its core and how the resulting movement occurs, the question aims to lead the respondents to place themselves in a situation where the notions of horizontality and verticality are relativized when thinking about the Earth as a whole, a situation in which, as the author states, one must conclude that "on Earth all horizontals are curved and verticals cannot be parallel" (Perelman, 1970, p.325).

Thus, probably due to the high average level of education of the respondents, the vast majority (60%) gave a satisfactory answer marking option (b) or (c), with practically equal incidences (30% each). However, the complete answer, in which the two situations listed in options (b) and (c) simultaneously occur, was marked by only two people. Furthermore, a 30% marked option (a), in which walking through this tunnel would be the same as walking on the Earth's surface. To help with this understanding, Perelman (1970) proposes an analysis of how long tunnels are constructed, in which it is necessary to account for the curvature of the Earth's surface to avoid water accumulation inside. The group that got this question wrong had an average score of 20% lower on questions 3, 4, and 5 in comparison to the entire group.

III.5 Analysis of Question 7 (n = 33) and 8 (n = 33)

Questions 7 and 8 have a historical and epistemological character. In the case of Question 7, the idea is to analyze how respondents conceive the famous experiment of Eratosthenes and how they think about the notion of "proof" in this case. In the context of the "fight" against Flat Earth theory, this experiment is often mentioned as unequivocal proof of the Earth's round shape. In these accounts, there is generally no mention of the assumptions from which Eratosthenes started, which aligns with an empiricist view in the construction of scientific knowledge. Consistent with this perspective, the option in which Eratosthenes proved the round shape of the Earth was chosen by only 10% of the subjects.

However, most of the responses (75%) indicated that he proved it based on theoretical assumptions. As many 20th-century philosophers of science concluded, scientific knowledge is always constructed from a theoretical perspective (Chalmers, 1993). More specifically, Lanciano and Berardo (2016), carefully analyzing the work and context of Eratosthenes, list four assumptions he made: (i) the Earth is round; (ii) Siena is at the Tropic of Cancer; (iii)

Alexandria and Siena are on the same meridian; and (iv) the Earth is so far from the Sun that the rays reaching the Earth can be considered parallel to each other.

The first assumption was what he aimed to prove. The next two can be confirmed by astronomical position measurements, although their confirmation of the tropic and the meridian already implicitly carries the idea of a round Earth.

The fourth assumption is the most interesting in this discussion and, at the same time, receives little attention. It depends on attributing the difference in the angle at which the rays hit the ground in the two cities and the Earth's sphericity. Objectively, this parallelism never occurs; the rays emitted by any light source always propagate divergently. Only if the source is very far away can we assume that divergence is negligible, and therefore, the sunlight that reaches us can be considered a beam of parallel rays.

However, we know the first accurate measurements of the distance between the Earth and the Sun occurred only in the 17th century. At the time of Eratosthenes, one could rely on the measurements of Hipparchus, for example, who, based on eclipses, compared the distance from the Earth to the Moon with the distance to the Sun. A century earlier, Aristarchus of Samos had estimated that the Sun was twenty times farther from the Earth than the Moon. Today we know it is nearly 400 times. Thus, the question is whether, in an emission coming from twenty times farther than the Moon, one could already assume a null divergence of the rays.

Here it is necessary to consider that part of these respondents (75% of the total) may have understood the word "prove" as internal corroboration to a theoretical model based on other assumptions, in this case, the parallelism of the rays of the Sun when hitting the Earth being due to the enormous distance that separates us, which points to the limitation of the questionnaire that discriminates relative positions.

In a manner more coherent with the epistemological framework that guides our discussions, 15% opted for the position that he did not prove it, because there were theoretical assumptions involved, which could only be corroborated much later, and mainly because starting from other assumptions, one could, with the same evidence, reach different conclusions, as Anaxagoras (500-428 BC) did.

In this matter, the quite significant agreement with a notion of theoretical dependence of observations seems to be, due to the constitution of the assistance, a result of the more consistent contact that students, teachers, and researchers currently have had with epistemological discussions. At the same time, the low incidence of the more relativistic option, associated with a contextual view of the acceptance of theories, beyond a dichotomous view (proved or not proved), even though the alternatives of the question induce this attitude, indicates the need for these epistemological reflections associated with historical studies to be enhanced. Azevedo et al. (2022), for example, argues that the work of Eratosthenes exemplifies the scientific method and considers his assumption about the parallelism of the solar rays hitting the Earth, but does so without highlighting the debatable nature of that hypothesis at the time.

In short, it is worth considering that scientists stand out less by the measurements and calculations, and more by the bold hypotheses they test, (Chalmers, 1993).

In Question 8, the intention is to provoke discussion about the novelty of the Flat Earth theory. An “attack” argument is that the flat Earth view was never present among educated people in civilizations such as the Babylonians, Greeks, Egyptians, and others (Russell, 1997). According to this author, especially in the Middle Ages, the Earth was considered flat. Without being a counterpoint, but a relativization of this generalization, Randles (1994), for example, analyzes the rapid transition in the representation of our planet from the notion of a flat Earth to a spherical one at the end of the 16th century.

In the same way, it is noteworthy that it is precisely from the Renaissance period that the oldest known terrestrial globe originates, built in collaboration with the painter Georg Glockendon by Martin Behaim between 1491 and 1493. The oldest description of the construction of a terrestrial globe, according to Azevedo (1965), would have been made by Strabo referring to the work of the geographer Crates of Mallus, who would have distributed four continents separated by oceans across the surface of a sphere, one of which was called ‘antipodes.’ According to Randles (1994), there still was discussion at the beginning of the Renaissance about the existence of people living on the other side of the ‘upside down’ Earth concerning the northern hemisphere.

In any case, it seems to us that the issue is interesting as it brings the expectators closer to a historical debate. Furthermore, from what Russell (1997) states, we can assume that uneducated people, those who interest us most here, may have difficulties dealing with Earth’s sphericity. The responses obtained show that Russell’s argument is strong, as half agreed with the idea of the flat Earth myth, either fully agreeing (5%) or agreeing while emphasizing that they do not know much about it (45%). Out of those who disagreed (35%), some did so without knowing much (20%) and others disagreed completely (15%). Fifteen percent did not know how to respond. Regarding the relationship between the answers to these two questions, it was found that option (b) in both presented the highest coincidence (11 people).

III.6 Analysis of Question 9 (n = 40) and 10 (n = 38)

Questions 9 and 10 have a strong didactic character. Question 9 investigates the implicit conception of learning in the way of considering a student’s conception who assumes the Earth to be flat, whereas Question 10 investigates the didactic treatment that would be most appropriate for this situation. Both originally form part of the dilemma proposed by Hashweh (1996) to openly question teachers, emphasizing the epistemological dimension of considering and addressing a flat Earth conception. Here, this dilemma was initially explored in a closed manner, with single and multiple choise questions (Harres, 1999) and more recently in an open manner twice, with opinion-based questions (Harres; Rocha; Henz, 2001; Bartelmebs; Figueira; Diel, 2023).

The current application occurred in a closed manner in Question 9 and in a multiple-choice manner in Question 10, as in this case, there was the possibility to choose between three of the ten options presented. All options for these two questions were taken (with minor modifications) from the open responses of pre-service teachers originally recorded in Harres, Rocha, and Henz (2001).

In Question 9, the options, from (a) to (d), reproduced statements that were considered coherent with four different conceptions of learning. The first three would be of an empiricist nature, according to Hashweh (1996), as they implicitly

> *emphasize the role of external reinforcement in learning, not believing that students internally develop ideas in science, being unaware of the existence of alternative conceptions, and being negligent when these exist* (p. 49).

Thus, it would be justified that a student at the end of Elementary School still thinks that the Earth is flat because there may have been an individual failure in understanding (option a) or because they have not yet experienced the teaching of this topic (option b) or, still, that the teaching of this content may have been deficient (option c). In all three cases, it is believed that if the student has experienced normal learning conditions and the teaching occurs adequately, there should be some level of learning.

The remaining option, which we call constructivist following Hashweh (1996), is linked to the respondent's recognition of the presence in the student's mind of an idea different from the one they want to teach and resistant to change. Implicitly, it is recognized that this idea would be the result of a construction by the student in their interaction with the surrounding environment. At the same time, the designation of 'error' points to a consideration of this knowledge as having a lower level in terms of its epistemological status, thus necessitating that it be eliminated and replaced.

In the responses, we found that the option for the erroneous idea being difficult to change was not the majority (35%). The majority chose the option in which the student had not experienced adequate teaching (55%). Ten percent of the subjects chose that the student did not have sufficient information as if they had not yet experienced the teaching of this topic. No one selected the option stating that they had a cognitive deficiency limiting their understanding.

In our previous research, as in Hashweh (1996), we found subjects who also recognized the relevance of this idea for the student through interaction with the environment, but they added relative acceptability to it, thus linking themselves to a less absolutist epistemological perspective. In the case of applying this questionnaire, we did not include this option due to its supposed attractive effect. Even so, this was possible, as at the end we included the option 'other' for each person to write what they thought. Four people recorded something, but unfortunately, when saving the file, what was written in this option was lost, which does not contribute to the percentages above.

In any case, as a limitation of the questionnaire and the conclusions we derived from the responses, it is necessary to consider that since the statement of the question asks for the most likely cause, it assumes that there would be only one cause. However, since the alternatives are not mutually exclusive, they can also contribute to the students' thinking, which indicates that it might be better to ask, for example, what the most important cause is in the respondent's opinion.

Question 10 presented a list of ten didactic strategies chosen from those presented by the interviewees in our first research (Harres; Rocha; Henz, 2001). In that publication, among the responses from a hundred subjects, we reproduced 18 of their strategies as representative of the four levels of didactic potential to promote a conceptual evolution of the student, according to Hashweh's classification (1996). Now, from these 18, we chose ten, some rewritten with slight modifications, also representative of this classification. Out of these, the respondents were to choose the three best for the learning objective. Table 2, below, presents the statements, ordered according to the classification in Hashweh's levels (1996) and the frequency with which each was chosen among the three marked options.

Table 2 – Recurrence of options in Question 10, ordered according to levels enunciated by Hashweh (1996).

Option	**Didatic action**	**Didatic perspective**	**f**
a	Make the most of student knowledge	Develop ideas	25
d	Propose conversations and debates so that students can relate their ideas to scientific concepts.	Develop ideas	35
b	Encourage him to look for a solution to the problem by "walking" with two fingers (like a small person) on a globe.	Refute ideas	5
j	Ask them to draw the Earth with the people living on it and show on the globe what the Earth is like.	Refute ideas	5
g	Make him observe the globe, comparing it with a world map.	Convince	5
c	Present examples that confirm the round shape of the Earth, such as a ship moving out to sea.	Convince	19
i	Show him the globe so he can see where we are.	Convince	2
h	Show space photos of the Earth so that the child understands what the Earth is like.	Convince	7
e	Ask them to search for information about the Earth in books or online.	Explain	4
f	Explain that their answer is incorrect and suggest that they observe the events around them.	Explain	7

In the last column of Table 2, it is noted that the highest-level strategies were significantly more marked than those of the lower levels. Out of the 44 respondents, only two did not mark options (a) or (d). Of these, 28 marked both and these subjects, except two, chose options linked to ‘convince’ or ‘refute.’ Thus, as in the previous three questions, the most likely reason for this is a sample bias involving a group with good experience and training in the assumptions involved in the questions, which are known to have received considerable attention in the field of science education.

Nevertheless, other inferences can still be made. For example, in general, the number of citations of strategies corresponding to the ‘convince’ level (27) was much higher than those for the ‘refute’ level of students’ ideas (10). This difference deserves analysis since the ‘refute’ level of didactic strategies presupposes the recognition and consideration of the existence of another idea in the students’ minds that is different from what is being taught. Even though this desire, in isolation, is linked to a simplistic conception of learning, whose objective would be to replace ‘wrong’ with ‘correct’ knowledge, it is very important and marks a differentiation between constructivist and empiricist conceptions of learning. In fact, a strategy aimed at ‘convincing’ the student that the Earth is round is linked to the latter conception. Thus, the question arises whether we are placing more emphasis on showing the evidence of the Earth’s round shape and less attention to what the students think.

Finally, it is worth noting that, unlike what was presented in Harres, Rocha, and Henz (2001), we did not find a correlation between the conceptions of learning investigated in Question 9 and the expression of pedagogical practices explored in Question 10. In that research, the presence of a more constructivist view of learning was generally accompanied by a strategy, consistent with that of a higher level (refute’ and ‘develop’). In our more recent work (Bartelmebs; Figueira; Diel, 2023), exclusively investigating future teachers, we found a higher incidence of empiricist strategies even when the conception of learning was shown to be more constructivist.

IV. Conclusions

In a general assessment of the questionnaire application, the overall data indicates that respondents have an adequate level of basic knowledge and initial positioning regarding the shape of the Earth, how children conceive this topic, and the most appropriate didactic strategies.

However, a lower level of reflection was also identified regarding some astronomical implications of the Earth’s sphericity, such as the percentage of flattening at the poles, which was generally overestimated. Such positions often appear associated with simplistic views on teaching and learning the topic, such as the belief that simply showing a school globe to a student would convince them of the Earth’s round shape.

These conclusions should be contextualized considering the limitations of the application method, which occurred during an event and was certainly also influenced by the limitations of the questionnaire, with questions varying in theme and response format. The lack of information about the subjects also limits the validity of the conclusions, as this would allow for stratified analyses and comparisons. Nevertheless, with some improvements – such as a better differentiation of the implicit didactic and epistemological perspectives – the questionnaire shows potential to foster these discussions and can be further refined.

Additionally, these preliminary findings indicate that, in the case of the Earth's shape, more integrated training in astronomical and didactic aspects is necessary, especially considering that the BNCC (Brazilian National Common Curriculum Base) currently advocates for an intensive approach to this and other astronomical topics from the early years of Elementary Education. In this process, it is essential to start from a conception where professional teacher training, to meet these demands, implies a process that goes beyond the simple addition or replacement of information, aligning with coherent action plans (Cubero, 1999; Porlán *et al*., 2011; Harres *et al*., 2012; Solís *et al*., 2016; Bartelmebs, 2016). Ultimately, the evolution of teachers' conceptions and practices toward greater consideration of students' ideas is a more complex undertaking than merely implementing an innovative training curriculum, as argued by Morrison and Lederman (2003) and Larkin (2012).

Finally, we hope that these reflections will allow us, following our investigations, to construct and propose more consistent didactic and assessment strategies for teachers and undergraduate students in the area. At the same time, we hope that the analyses and discussions presented here, in the search for more teaching and learning about astronomy at school, will favor the development of a less absolutist view of the shape of our planet and a more critical view of denialism in general.

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Appendix: Questionnaire

1) What is the shape of the Earth?
a) Flat b) Spherical c) Oblate spheroid (flattened at the poles) d) Other

2) Among the reasons listed below, mark the one you consider having the greatest influence on the fact that many people currently believe the Earth is flat:
a) It aligns with our everyday view.
b) General population's low level of education (completion of school degrees).
c) Lack of information.
d) Lack of consideration and discussion of alternative ways of interpreting reality in school learning.
e) Uncritical persuasive power of the media.
f) Psychological attraction to thinking differently from others to believing that one knows something no one else does, that there is a group manipulating us, etc.
g) Other, different from the above.

3) The Earth's radius is smaller at the poles than at the Equator. This percentage difference is most accurately expressed as:
a) 0.001% b) 0.01% c) 0.1% d) 1% e) 10%

4) Generally, school globes do not show the Earth's relief or the flattening at the poles. The paper covering them, with the drawing of the continents, is "smooth." If a manufacturer of school globes like the one in the photo wanted to represent the Earth's relief, Mount Everest (9 km above sea level) would, in terms of order of magnitude, have a height of a few:
a) Micrometers (thousandths of a millimeter) b) Hundredths of a millimeter
c) Tenths of a millimeter d) Millimeters e) Centimeters f) Decimeters

5) A boat, whose highest point is 5 meters above sea level, moves away from a beach and disappears over the horizon for an observer standing there. The value that best expresses the approximate distance from the beach at which the observer can no longer see the boat is:
a) 1 km b) 3 km c) 10 km d) 30 km e) 60 km f) 100 km

6) What would it be like for a passenger traveling on a train through a straight and very long tunnel, for example, connecting São Paulo to Rio de Janeiro (450 km)?
a) It would be the same as traveling on the horizontal surface of our planet.
b) It would be different. In the beginning, there would be a sensation of descending a slope, and from the halfway point, the sensation would be of ascending it, tantamount to descending into a valley and then climbing up the other side.
c) It would be different. As we get closer to the Earth's center, we would feel strong acceleration (like during an airplane takeoff), and from the halfway point, we would feel a sensation of being pulled backward (like when an airplane brakes hard during landing).
d) It would be different, and we would feel both sensations described above.
e) Other

7) As far as is known, Eratosthenes (200 BC) was the first to “measure” the Earth’s radius. According to some authors, he “proved” empirically that the Earth is round because he did not rely on any theoretical assumptions. Do you agree with this account of Eratosthenes’ work?
a) Yes, he proved it because empirical evidence dispenses with theoretical assumptions.
b) Yes, he proved it, but he certainly started from some theoretical assumption.
c) He did not prove it because theoretical assumptions were involved. With the same evidence and starting from other assumptions, one could prove that the Earth is flat.
d) He did not prove it, but I don’t know why.
e) Other

8) Regarding the claim that the flat Earth idea was dominant in the Middle Ages, many authors argue that this is a “myth” because, according to them, any educated person in that period would certainly have had access to the knowledge of the Greeks and other civilizations, who had even “measured” the Earth’s radius. How much do you agree with the idea that people did not think this way in the Middle Ages?
a) I completely agree.
b) In principle, without knowing much about it, I agree.
c) I don’t know what to think.
d) In principle, without knowing much about it, I disagree.
e) I completely disagree.

9) If a student at the end of Elementary School still believes the Earth is flat, it is most likely because:
a) They have a cognitive deficiency that prevents them from keeping up with their peers.
b) They do not have enough information.
c) They have not experienced adequate teaching of this content.
d) This incorrect idea is very “strong” in them.

e) Other

10) Mark the three best didactic strategies listed below to promote learning about the shape of the Earth:

a) Explore the student's knowledge to the fullest.

b) Encourage them to find the solution to the problem by "walking" two fingers on a globe (like a tiny person).

c) Present examples that confirm the Earth's round shape, such as a ship moving away from the coast.

d) Propose conversations and debates, guiding the student to relate their ideas to scientific conceptions.

e) Ask them to research information about the size and shape of the Earth in books or online.

f) Explain that their answer is incorrect and suggest they observe events around them.

g) Have they observe a globe, comparing it to a world map.

h) Show them space photos of the Earth so they can understand that it is round.

i) Show them the globe to see where we are located.

j) Ask them to draw the Earth with people living on it and show them on the globe what the Earth is like.