Children's representation of the Earth at the end of elementary school: the role of spherical and geographical information carried by the globe

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Abstract

Children's representation of the Earth is usually analysed from an astronomical point of view. In our study, we used a globe to support children reasoning and we distinguished the impact of the two types of information that it carries: spherical and geographical. Children (aged 11 years) performed tasks with a regular globe or a blank globe. The results showed that children performed better in the presence of geographical information. In French education, the shape of the Earth is taught independently in science and geography classes whereas our study shows that these two fields are intertwined to support the representation of a spherical Earth.

Keywords

Earth, knowledge, globe, astronomy, geography

Résumé

La représentation de la Terre est généralement analysée du point de vue astronomique. Dans notre étude, nous utilisons un globe pour supporter le raisonnement des enfants et nous distinguons l'impact des deux types d'informations qu'il porte : la forme sphérique et la répartition géographique des continents. Des enfants âgés de 11 ans réalisent deux tâches avec un globe normal ou avec un globe blanc. Nos résultats montrent que les élèves réussissent mieux en présence d'informations géographiques. Dans l'enseignement français, la forme de la Terre *est abordée indépendant en science et en géographie alors que notre étude montre que ces deux domaines se complètent pour soutenir la représentation sphérique de la Terre.*

Mots clés
Terre, connaissance, globe, astronomie, géographie

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Introduction

Ancient Greeks discovered that the Earth was round; however, the myth of the flat Earth persists (Giacomotto-Charra & Nony, 2021). In the collective imagination, we continue to think that people in the middle age believed in a flat Earth. This myth is consistent with children's early knowledge and their direct experience of Earth. The fundamental properties of the Earth (shape, rotation, gravitational force, etc.) refer to complex notions. For example, how can we conceive that, if the Earth is spherical, people who live at the antipodes do not have their heads upside down? Direct observation of nature does not allow children to acquire the necessary knowledge to answer such a question. In this case, appearances are deceptive, and knowledge is counterintuitive. This acquisition cannot be an individual construction but relies on cultural and educational contributions. Many studies have focused on the way children represent the Earth and have offered more complex analyses than the simple belief in a flat Earth. The nature, organisation, and evolution of this initial knowledge are the subject of debate. In what follows, we briefly go through the stages of this debate and participate in it with a new hypothesis and a new experimental approach.

Theoretical framework

Stages of the debate

In the 1990s, Vosniadou and Brewer (1992) assumed that children's knowledge was organised very early in mental models, comparable to naïve theories. For example, some children think of Earth as a flat disc or a hollow sphere with people in it. These mental models are embedded within a deeper presupposition, such that the ground on which we live is flat, and the space is organised in up-and-down directions. These mental models have internal coherence and act as explanatory systems. Diakidoy et al. (1997) show through a multicultural study that these presuppositions are universal because, regardless of the cultural background, they agree with the local vision of the Earth that a child experiences every day. Diakidoy et al. (1997) further show that the process of evolution of mental models is also universal and follow three stages: naïve mental model, then synthetic mental model (reflecting children's attempt to reconcile basic presuppositions and new scientific information) and finally scientific model.

These studies were based on the same methodology. School-age children were asked open questions about the Earth during an individual interview. While some questions are factual ('what is the shape of the Earth?'), most are generative and confront the child with an unfamiliar situation for which they may not have memorised a ready answer ('if you walked for many days in a straight line, where would you end up?'). This question requires the child to make productive use of whatever knowledge (scientific or otherwise) they have. The interview also offered drawing tasks ('draw the Earth. In your drawing, show where the Moon and the stars go'). The authors of these studies generated six different mental models of the Earth and claimed that it was possible to identify a relatively well-defined model for the majority of children.

In the 2000s, many studies challenged this vision of organising young children's knowledge into mental models based on presuppositions (Frède et al., 2011; Nobes et al., 2003, 2005; Panagiotaki et al., 2006; Schoultz et al., 2001; Siegal et al., 2004). The authors defended the perspective of more intuitive physics, as described by diSessa (1988). Intuitive knowledge is a fragmented set of ideas called phenomenological primitives, which generally need no explanation and form no logical or coherent chains. Young children do not have a naïve theory or mental model of the shape of the Earth but largely improvise an answer using different pieces of knowledge at the time of formulation. diSessa (1988) found that students seldom committed strongly to any particular interpretation. This view of conceptual change involves a gradual enrichment of knowledge by accumulating 'fragments' and not a radical restructuring. Cultural contributions and education make it possible to sort, enrich, and gradually organise children's fragments of knowledge into scientific theories.

In the particular case of the representation of the Earth, the results obtained using the two approaches lead to contrasting results. The mental model approach leads to lower performance than the fragmentation approach. These variations are probably due to differences in the methods. On the one hand, proponents of mental models interviewed children with open-ended questions that were difficult to interpret and drawing tasks that were, then, interpreted as faithful reflections of children's knowledge. On the other hand, proponents of knowledge in pieces proposed forced-choice questions and recognition tasks that did not require a real understanding of the phenomenon. The low performance of the children observed by Vosniadou and Brewer (1992) could be explained by the difficult and confusing questions and the absence of contextualisation that could affect a viewpoint. Let us expand on some of these criticisms.

Using the same set of questions used by Vosniadou and Brewer (1992), Nobes and Panagiotaki (2007) showed that both children and adults could generate the same naïve mental models. Nobes et al. (2023) have even detected naïve mental models in adult participants who are expert astronomers. They observed that many of these competent adults made naïve drawings of the Earth and that half of them gave naïve answers to the questions. This finding indicates that both children and adults can misinterpret the point of the task and suggests that poor performance is not due to a lack of knowledge about the Earth but to a poor understanding of the task. This study showed, in particular, semantic issues with the meaning of the instructions. The importance of vocabulary has already been highlighted in the case of gravity (Clerk & Rutherford, 2000) and the case of the distinction between the weight and mass of a body (Baldy, 2007). For their part, Siegal et al. (2004) found no difference in children's performance when asked about the shape of the 'Earth' (which refers to both the planet and the ground we walk on) or the shape of the 'world'. This misunderstanding can also be linked to the ambiguity of the viewpoint induced by the questions. Nobes and Panagiotaki (2007) note that questions such as 'where is the sky?' or 'if you walked for many days in a straight line, where would you end up?' lead to different answers depending on whether a viewpoint is adopted. To overcome these ambiguities, Nobes and Panagiotaki (2009) and Panagiotaki et al. (2009) propose a reformulated set of questions in which each question is contextualised. They observed that performance improved in both adults and children. Jelinek (2020) notes that the viewpoint induced by the question influences the shape of the Earth that children proposed. When asked to make the Earth with modelling clay, the majority of Polish children aged 5-8 years formed a sphere. However, when then asked to place Lego minifigures to show where people live, several children crushed their ball of clay to make a flat surface and place people on top.

Nobes et al. (2003), Siegal et al. (2004), Nobes and Panagiotaki (2007), Straatemeier et al. (2008), and Ehrlén (2009) have also commented on the drawing task. Vosniadou and Brewer (1992) interpreted the drawings of people standing in a line as being guided by the presupposition of flatness and the need for support. However, the low scores on the drawing task may be attributed to the inability of children to draw a correct picture (to combine different scales, to draw 3-dimensional objects, to choose a single perspective) rather than to a lack of knowledge of the Earth. Previous analyses lean on the theory of children's drawings from Luquet (1927) who differentiates between stages of intellectual and visual realism. At the stage of intellectual realism, children try to depict an object by showing its important details that they know of, regardless of whether the details are visible. At the stage of visual realism, children try to depict an object from a particular perspective. If children attach to an intellectually realistic mode of depiction, their drawings are unlikely to accurately represent their views of the Earth.

The methods used by mental model theorists have also been criticised for analysing children's answers. Vosniadou and Brewer (1992) compared each pattern of answers with those that would occur if children had well-defined mental models. The authors assigned more than 80% of the children to particular mental models. However, this technique can lead to overestimated consistency. Nobes et al. (2003), Siegal et al. (2004), Straatemeier et al. (2008), Hannust and Kikas (2010), and Frède et al. (2011) note that a pattern of answers can only be classified as 'consistent' if it occurs more often than expected by chance. To test this possibility, patterns of responses were investigated to assess whether they were best predicted by a mental model account or by a probabilistic distribution. According to this analysis, combinations of answers consistent with a mental model do not occur more frequently than by chance or other combinations.

Role of cultural artefacts

Studies in the 2000s have also focused on the cultural dimension of children's knowledge. Knowledge about the shape of the Earth cannot be acquired through direct observation but is transmitted from cultural resources. Frède et al. (2017) have shown that the proportion of flat Earth or hollow Earth is higher in a group of Burkinabe children who live in an animist culture than in a group of French children. Frède et al. (2011) highlighted the role of informal information. Comparing their findings with those of Vosniadou and Brewer (1992), they observed that French children performed better than American children, even though they asked the same questions and used the same method of analysis. They interpret this change in children's knowledge as the effect of greater exposure to cultural communication, for example, due to the Internet and television. Troadec et al. (2009) have noted that while the knowledge of the globe as a representation of the Earth appears obvious to Western children as early as 6.5 years of age, this is not the case for Moroccan children who only acquire this understanding at around 10.5 years of age, which corresponds to the age at which astronomy is taught in Morocco. Siegal et al. (2004) also confirmed the key role of education. The authors observed that young Australian children, who were exposed very early to astronomy at school, were significantly advanced compared to their English counterparts. The differences were eliminated by the age of eight, which coincides with the introduction of geography and astronomy into the English school curriculum. Similarly, Nobes et al. (2003) have shown that the knowledge of British and Asian classmates in London schools is comparable, as they are taught in the same way.

The introduction of a cultural artefact such as the globe during the interviews led to another aspect of the debate. Schoultz et al. (2001) chose to conduct interviews using a globe with 25 Swedish children aged 6-11 years. They showed that all participants could identify the globe as a representation of the Earth and took it for granted that people could live in both hemispheres without falling off. When a cultural artefact like the globe supports their reasoning, children mobilise sophisticated knowledge and can accomplish complex reasoning about the Earth. Vosniadou et al. (2005) and Skopeliti and Vosniadou (2007) also studied the effect of using a globe to support children's reasoning. The results showed an increase in answers compatible with scientific knowledge and a decrease in the overall consistency of the answers. Thus, the presence of the globe imposes a scientific model of the Earth on children. Finally, we can mention the study by Ehrlén (2008), who formulated the same criticism of the task of determining the shape of the Earth using a globe as she formulated for the drawing tasks. Similar to drawing, the globe can be interpreted according to the conventions of intellectual or visual realism. Ehrlén has noted that several children aged 6-8 years recognise the globe as a representation of the spherical Earth, while later in the interview, they provide responses consistent with a representation of a hollow Earth. The author assumed that these children interpreted the globe in an intellectual realist mode of depiction: the continents are inside the Earth but can be seen through the globe through transparency.

These observations show that the use of a cultural artefact such as the globe is helpful, but it is not sufficient to impose scientific knowledge. The information it carries needs to be interpreted by children; therefore, it can be misinterpreted when it conflicts with children's alternative knowledge.

Originality of our study

The studies mentioned above have shown how children's prior knowledge influences the way they use the information carried by the globe. However, what information are we talking about? The globe carries two types of information from two different school curricula: spatial information about the spherical shape of the Earth from astronomy lessons and geographical information about the distribution of continents, countries, and people from geography lessons. It is likely that this knowledge acquired at school strongly influences the way children interpret and use the globe. However, to the best of our knowledge, no previous study has clearly separated these two types of information. A closer analysis of the protocols reported by Schoultz et al. (2001) shows that children's responses can be situated within a geographical thinking framework. For example, to answer the question 'do people live in Australia?', children could mobilise geographical knowledge about Australia. Therefore, they find it natural for people to live in Australia. They have seen Australians on television before and have seen that they are not upside-down. In support of this hypothesis, a little girl (Erica, p. 113) reported that she knew that there were fires in Australia at the time of the experiment, which was cultural knowledge probably acquired through television. Similarly, Vosniadou et al. (2005, p. 349) reported that when asked the question 'can people live here at the South Pole?', many children bent to look under the globe to see if there was a country there. Upon seeing the South Pole, they answered that people could live there. Clearly, in answering the questions, children did not rely on their representation of the shape of the Earth but based their answers on the presence of geographical clues: the presence of continents drawn on the globe. These answers show that children have a good understanding of the geographical information carried by the globe but do not tell us anything about how they represent the Earth or even whether their responses are based on any representation of the shape of the Earth. Kampeza and Ravanis (2009) confirm that even preschoolers chose among different three-dimensional bodies painted in green and blue the spherical one and that almost all children distinguished between land and sea. Their study futher showed that, during an educational intervention, the combination of the geophysical features of the Earth's surface (land, sea, mountain, river...) with the shape of the Earth could improve the representation in both geography and astronomy. It is therefore of great theoretical importance to take into account the role of these two types of information carried by the globe, especially as we might consider that geographical information, which has been neglected in the previous analyses, may be the cause of the dramatic improvement of children's performance. Our study aimed to determine the respective roles of these two types of information. More specifically, our study attempts to answer the following two research questions:

Question 1: In the presence of a globe, do children mobilise a spherical representation of the Earth?

Question 2: The improved performance of children using a globe could be assigned not to the mobilisation of a spherical representation of the Earth but to the mobilisation of geographical knowledge. What is the relative impact of these two types of information on children's performance?

Methodological framework

Sample

Thirty participants attended the experimentation. They were divided into 2 groups of 15 that performed the proposed tasks under 2 different conditions (with and without geographical information on the globe). The proportion of girls and boys in each group was balanced. The participants have been selected in fifth grade (average age: 10 years 8 months) because, at the end of elementary school, they all attended astronomy classes, in which they discussed the shape of the Earth and its movements, geography classes, in which they described and named some of the characteristics of the continents, and mathematics classes, in which they constructed a representation of space. The participants came from a school with a mixed social profile representative of a state primary school in a medium-sized French town. They were in their normal school year. Parents were informed and consent was obtained by a note in the child's notebook. Each child gave verbal consent at the beginning of the interview.

Materials and procedure

Children were shown a world map and one of the two globes, as shown in Figure I. The world map used a Mercator projection, measured 28x20 cm, and was printed in colour on an A4 sheet of paper presented horizontally. The sea was shown in blue, and the countries were in different colours with their names. The equator was overdrawn in black, and the Greenwich meridian was in red. Five coloured stickers were added: yellow for France (Paris), red for South Africa (Cape Town), green for Japan (Tokyo), blue for the West Coast of the United States (Los Angeles), and pink for New Zealand (Auckland). Both globes were 8.5 cm in diameter. Their circumference approximately matched the size of the world map. One of the globes, called the regular globe, showed classic geographical information. The other globe, called the blank globe, had an even white surface. On both globes, the equator was overdrawn in black, and the Greenwich meridian was in red.

FIGURE 1

Materials used during the interviews: a world map with five stickers and a regular and a blank globe

The same experimenter interviewed the children individually in a classroom adjacent to their usual classroom. Detailed notes and pictures of children's productions were taken during the 10 minutes of a structured interview. Children were informed beforehand that they would be asked a set of questions about the Earth to help the experimenter investigate their understanding of the Earth. The procedure consisted of three tasks, as shown in Table 1.

TABLE 1

Questions asked in the three successive tasks

Introduction (Task 1):
Q1: Choose among these 6 models the one that has the same shape as the Earth.

Q2: (showing the world map and, then, the globe): *What is this? What does it represent?*
Q3: *Can you show me France with your finger?*

Location (Task 2):
On the world map, there are five different coloured stickers in five different places. Here are five stickers, put them back on the globe in the corresponding places, keeping the colour code.
At the end of the task (on the globe): *show me with your finger where people can live.*

Route (Task 3):
Step 1 (on the world map): *A man lives here (the green Tokyo sticker was shown), and he wants to go here (the blue Los Angeles sticker was shown). He can take a plane. Show me the shortest route he can take on the world map.*
Step 2 (on the globe): *Show me the shortest route on the globe. Could the man go that way (pointing to the Pacific route)?*
Step 3 (on the world map): *Now show me this route on the world map.*

In Task 1 (introduction), we asked the children about their recognition of the artefacts. First, children have to choose, among six 3D shapes, the one that 'has the same shape as the Earth'. This question was exclusively about the shape of the Earth, which is why the 3D shapes were blank. The six shapes were chosen to cover the children's possible responses: a spherical Earth and five different interpretations of the Earth's flatness. However, we assume that at this point in the interview, the spherical Earth will be largely chosen by the 10-year-old children. The tasks that follow will show whether the children are able to use this spherical representation of the Earth in an operative way. Then, they were asked to name and say what the world map and the globe represent to ensure that its artefacts are indeed representations of the

Earth in the minds of children. Finally, the children were asked to show France on the world map.

Previous studies (see also Nobes et al., 2003) have shown that children's language skills play an important role in understanding questions. The following tasks are longer and more complex than the usual questions, but they are less ambiguous and involve fewer language skills.

In Task 2 (location), children were shown the five stickers on the world map. They were, then, given five stickers to place on the corresponding location on the globe (the regular globe or the blank globe) while maintaining the colour code. The globes were always presented with the Greenwich meridian facing the child. At the end of the task, the children were asked to show where people could live. Depending on the child's response, we asked 'can people live here?', pointing to the southern hemisphere and/or the opposite side of the globe.

In Task 3 (route), children were shown the green sticker for Tokyo and the blue sticker for Los Angeles on the world map. The task was divided into three steps. In the first step, the children had to show the shortest route from one place to the other on the world map. In the second step, they had to show it on the globe; either the stickers had already been placed correctly on the globe, or we placed them in the right places without comment. If the children did not show the shortest route, we asked them whether the man could go this way, pointing to the shortest Pacific route. If the answer was positive, children were asked, in the third step, to show this route on the world map. Tasks 2 and 3 required children to combine the flat representation of the Earth on the world map with its spherical representation, that is, the globe. Both tasks will allow us to determine whether children mobilise a spherical representation of the Earth when using a globe. Do they distribute stickers all over the world? Are they able to find a way on the world map that goes behind the globe? The two modalities (regular globe vs. blank globe) allowed us to determine the effect of geographical information.

The operational hypothesis is that children's performance will be lower with a blank globe, where geographical information has been deleted, than with a regular globe.

Scoring

For Task 1, we only recorded success or failure on each question. For Task 2, the data were scored twice: first, we gave each child a score from 0 to 5 according to the number of stickers placed in the right place; then, we scored 'success' when children placed four or more stickers in the right place. For Task 3, children were considered to have failed when they did not show the shortest route on the map and to have succeeded when they showed it at the beginning or end of the task. For Tasks 2 and 3, we also analysed the strategies and justifications used by children. The results are analysed statistically with non-parametric tests to determine whether there is an artefact effect.

Results

Results of Task 1 (introduction)

Table 2

Children's responses to Task 1 and their frequency

	Children's responses to Task 1	
Q1	Choice of the sphere	30
Q2	Recognition of the world map Recognition of the globe	25 30
Q3	Location of France on the regular globe	30

As shown in Table 2, Task 1 was generally well performed by the children. In Question 1, all the children chose the sphere. They named it either a ball or a circle. For Questions 2 and 3 on the recognition of artefacts, we observed that all children said that the globe represented the Earth and that the majority of children said that the world map also represented the Earth or the countries on the surface of the Earth (p=0.0001). Only a few children thought that the world map represented only a part of the Earth. Notably, the children generally did not use the appropriate vocabulary ('planisphère' in French or 'globe'). All children located France on the world map.

Results of Task 2 (location)

Table 3

Success and strategies in Task 2 (location) and their frequency

Globe	Strategies	Success 4 or 5 stickers		Failure 3 or fewer stickers		Average score
Regular Globe	Geo-sphere	10	15	0	0	5
	Geo-clues	5		0		
Blank Globe	Spherical	4	4	2	11	2.93
	Flat	0		9		

Children's success and strategies in Task 2 and their frequency are shown in Table 3. Initially, the data appeared to show that children using the regular globe succeeded more often than children using the blank globe. We see that all children using the regular globe located the stickers correctly (15/15), whereas only four of the fifteen children using the blank globe managed to place four or five stickers correctly. A median test carried out on the scores from 0 to 5 obtained by the children confirms an artefact effect (p=0.00003). In accordance with our hypothesis, more stickers are correctly located on the regular globe in the presence of geographical information than on the blank globe in the absence of geographical information.

During the interviews, we observed the children placing stickers and took notes of what they said and did. We, then, determined *a posteriori* the following four strategies (geo-spherical, geo-clues, spherical, and flat).

In the regular globe modality, we defined two strategies:

<u>The 'geo-spherical' strategy</u>: children relied on both geographical information carried by the regular globe and the spatial relationships between the world map and the globe. We observed that the children positioned the stickers quickly and in the right locations all over the globe. We could, therefore, think that their geographical knowledge and spatial representation skills led them to establish the appropriate relationships between the world map and the globe. The relative influence of these two types of knowledge on their reasoning cannot be discriminated against.

<u>The 'geo-clues' strategy</u>: children looked for visual clues such as the shapes, sizes, colours, and names of countries all over the globe without apparent logic. We observed children fumbling around, going back and forth between the world map and the globe to compare the names, shapes, and colours of the countries. However, they ended up placing the stickers in the correct locations.

As Table 3 shows, in the regular globe modality, neither strategy was used more significantly than the other (p=0.151), and both led to success.

In the blank-globe modality, we defined two other strategies:

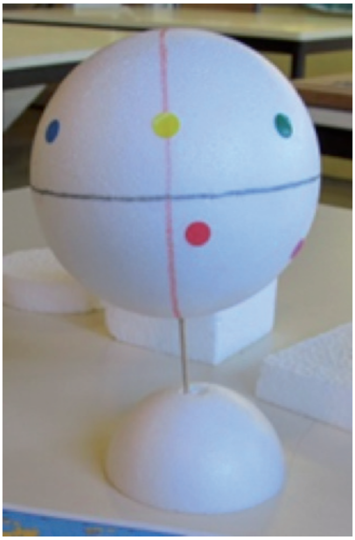
<u>The 'spherical' strategy</u>: children used the whole surface of the globe to place the stickers. The spatial relationships between the flat world map and the spherical globe were sometimes mastered (the five stickers were correctly located, four children in Table 4a) and sometimes remained incomplete (only three of the stickers were correctly located, two children in Table 4a).

<u>The 'flat' strategy</u>: children projected the flat world map onto the half-sphere of the globe facing them. They stuck the stickers in this 'pseudo' plan by locating them in the 'pseudo' Euclidean space set by the equator and the meridian drawn on the globe. The stickers were located quickly but only on the anterior half-sphere of the globe, as shown in Figure 2. The respective positions of the stickers were respected but in an inappropriate frame of reference that did not consider the sphericity of the globe. Children generally scored 2 (9 children in Table 4a) for the 2 stickers closest to the 'Euclidean space axes' (Paris and Cape Town), whereas the 3 stickers, which were furthest away, were poorly positioned. Table 4b shows that the five stickers are not placed

with the same success. They could be divided into two groups, with stickers close to the axes (Paris and Cape Town) more often located correctly than those further away (Tokyo, Los Angeles, and Auckland) (χ^2=29.77, p=0.000).

Neither strategy was used more significantly often than the other (p=0.5). The 'spherical' strategy led half of the children to succeed and half to fail. The 'flat' strategy, of course, led all children to fail.

FIGURE 2



A 'flat' strategy, the stickers were located on the half-sphere facing the child

TABLE 4a

In the blank-globe modality, the numbers of stickers correctly located

Number of correctly located stickers	Frequency
0	0
1	0
2	9
3	2
4	0
5	4

TABLE 4b

In the blank-globe modality, the numbers of children who correctly located the sticker

Location	Frequency
Paris	15
Cape Town	14
Tokyo	4
Los Angeles	5
Auckland	6

Concerning the distribution of inhabitants on the globe that closed this task, we observed an artefact effect (χ^2=6, p=0.014). With the regular globe, children distributed inhabitants all over the continents without difficulty, while with the blank globe, five children said that there could not be any inhabitants 'behind' the Earth: '*there is nothing behind*', '*there is water*', '*it is not the Earth*', and so on. All these children had proposed a 'flat' strategy while locating the stickers.

Results of Task 3 (route)

TABLE 5

Response patterns and success in Task 3 (route) and their frequency

Response Patterns		Route on the world map Step 1	Route on the globe Step 2	Route on the world map Step 3	Regular Globe	Blank Globe	Total
1	Success	+	+	+	1	7	25
2		-	+	+	4	2	
3		-	proposed	+	10	1	
4	Failure	-	+	-	0	5	5

In Table 5, patterns 1, 2, and 3 involving 25 children are success patterns. In Pattern 1, children succeeded directly. In Pattern 2, children first visualised the Pacific route on the globe before transposing it onto the world map. In Pattern 3, the interviewer proposed the Pacific route on the globe to the children. Under certain conditions, these 25 children mobilised a spherical representation of the Earth to complete the task. Patterns 1 and 3 have attracted our attention. In Pattern 1, seven of the eight children, who showed the shortest route across the Pacific in the first stage, were interviewed with the blank globe, which was the majority (p=0.031); half of the children used this globe. In Pattern 3, of the 11 children helped by the interviewer, 10 were interviewed with the regular globe, which was the majority (p=0.005); two-thirds of the children used this globe. Children answering with the blank globe seemed more likely to spontaneously mobilise a spherical representation of the Earth than those working with the regular globe.

Pattern 4 is a failure pattern. These five children showed the Pacific route on the globe but did not find or accept that the traveller could take this route on the world map. They all used the blank globe. They were unable to mobilise a spherical representation of the Earth to complete the task.

A χ^2 test conducted on children's success and failure shows an artefact effect (χ^2=6, p=0.014). Children interviewed with the regular globe succeeded more often than those interviewed with the blank globe.

Let us analyse the justifications offered by children for accepting or not accepting the Pacific route. The eight children who spontaneously showed the Pacific route on the world map (Pattern 1) justified their answer by referring to the sphericity of the Earth, sometimes by relying on the artefacts ('*if I roll up the sheet, the two points touch*') and sometimes by relying on the 'real' Earth ('*the Earth is round, so you can go around*'). We could, therefore, think that these children understood the world map as a development of the globe and were capable of mentally representing this spatial operation. The other 17 children who accepted the Pacific route (Patterns 2 and 3) also justified their answer by referring to the spherical shape of the Earth. Some children based their reasoning on the world map only: *when you get there (point to the right end of the sheet), you are on the same side as there (point to the left end)'*. Other children distinguished, in their justification, between the artefact and the 'real' Earth: '*on the map, it's cut, but on the real Earth, you can*'. Therefore, they were aware that the world map was only an inaccurate representation of the Earth. We could think that these children remained prisoners of the flat representation of the Earth carried by the world map at the first step of the task but were able to mobilise a spherical representation of the Earth and establish the appropriate spatial relationships when the presence of a globe helped them to do so.

Among the five children who refused the Pacific route (Pattern 4), Aurélien[1] told us: '*we can go around (probably the sheet), but it's very long*'. This child relied only on the world map, which did not seem to have any link with the real Earth. Khava and Océane based their reasoning on a personal and naïve representation of the Earth: '*No! You can't go through there, it is not the Earth!*' and '*when you get there, you can't go anymore'*. The boundaries of the world map meet the boundaries of the Earth.

1 The names of the children used in the article have been changed.

Children's consistency in tasks

Notably, out of the 30 participants, 19 children successfully completed both tasks. Thus, two-thirds of the children came up with coherent answers compatible with scientific knowledge. Table 6 presents the cross-tabulated success in the two tasks, that is, location and route, in the blank-globe modality only to focus on children who only had spatial information to support their reasoning.

TABLE 6

Success and failure on Tasks 2 and 3 (location and route) in the blank-globe modality

		Task 3 (Route)	
		Success	Failure
Task 2 (Location)	Success	4	0
	Failure	6	5

McNémar's test showed that children answered differently to the two tasks (χ^2_{McN}=4.16, p=0.041). While all those who failed Task 3 also failed Task 2, some who failed Task 2 succeeded in Task 3. This suggests that Task 2 is particularly difficult in the blank-globe modality. Without a solid and operative spherical representation of the Earth, it cannot be achieved. Task 3 was probably not as demanding. Notably, the five children who did not distribute inhabitants all over the globe in Task 1 (Table 2) failed both tasks.

DISCUSSION

The present study aimed to answer two questions: First, in the presence of a globe, did children mobilise a spherical representation of the Earth? Second, did children base their reasoning on this representation alone or did the geographical information provided by the globe help? Three tasks were presented to the participants. The first task was essentially declarative, while the other two were complex and required a solid and operative spherical representation of the Earth in the blank-globe modality. We, first, answer these two questions and, then, consider the implications of these new results.

Main results and interpretations

In Task 1, all children chose the sphere and told us that the Earth was round or similar to a ball. Most of them recognised the world map and the globe as representations of the Earth, and they all managed to locate France. All children, thus, seemed to know that the Earth is spherical and had some geographical knowledge of the continents and the position of France. However, in the following tasks, the declarative knowledge 'the Earth is round' has to become operative knowledge that supports the reasoning.

In Task 2 with the regular globe, children aged 11 were all successful, using either a spherical representation of the Earth or geographical clues. They were also all successful, either directly or after using the globe, in Task 3. This finding suggests that children finishing elementary school have constructed the spatial and geographical information carried by the regular globe and the world map and know how to establish the relations between the two. With the blank globe, only four children succeeded in the location task by using a spherical strategy, and nine children failed by using reasoning based on a flat representation of the Earth. This dramatic decline in children's performance suggests that the lack of geographical information on the blank globe is an insurmountable challenge.

How to interpret these results? With the regular globe, all the children used geographical information. Some of them reasoned exclusively on this basis, looking for visual clues on the globe, which exempted them from mobilising a spherical representation of the Earth. Thus, introducing a globe into a task does not necessarily impose an astronomical scientific framework. The globe involves knowledge of different natures, particularly geographical knowledge. With the blank globe, in the absence of geographical information, the children had no choice but to mobilise a spherical representation of the Earth. Only four children succeeded, and the others adopted a flat Earth strategy that led to failure. In other words, when the spherical strategy was not constrained, the search for geographical clues allowed for success, and when it was constrained, most of the children failed. Observations suggested that the children who reasoned according to a flat representation of the Earth failed to consider the part of the globe that they could not see. They projected the world map onto the half of the globe facing them, without considering the hidden part of the globe. Thus, some children may choose the sphere and describe the Earth as round or spherical (Task 1) but rely on a flat representation of the Earth to locate positions on the globe (Task 2) and consider that the route stops at the edge of the sheet and/or the Earth (Task 3). The presence of a blank globe does not allow these children to make the spherical Earth operative knowledge. Contrary to what one might think, it seems that by looking at the globe, they do not necessarily conceive that the Earth is round. Faced with a blank globe and no geographical clue to encourage the children to consider the whole sphere, sphericity remains implicit and does not become an operative property. These results allow us to refute the interpretation made in previous research that the presence of a globe encourages children to place themselves in the scientific framework of a spherical Earth. Instead, they show that when given the opportunity, children exploit geographical clues.

The children's performances with the regular globe are consistent with the observations of Schoultz et al. (2001), Vosniadou et al. (2005), and Skopeliti and Vosniadou (2007), who reported sophisticated knowledge about the shape of the Earth from the children interviewed in the presence of a globe. However, our two main results (the differences in performance between the two modalities and the description of strategies) open up new interpretations of the children's responses. The successes are not exclusively based on sophisticated knowledge of the spherical shape of the Earth but on coordination between knowledge of the shape of the Earth and geographical knowledge, such as the distribution of the continents on its surface. This use of geographical knowledge explains why even children who do not mobilise a spherical representation of the Earth have no difficulty locating stickers 'upside-down' in the southern hemisphere (Vosniadou & Brewer, 1992). Their answers are not supported by the presuppositions of an up-and-down organisation of space but through geographical knowledge: there is a continent at the South Pole; thus, there may be inhabitants. The remark by Vosniadou et al. (2005, p. 349) that children bent to look under the globe to see if there was a country there before answering the question took on a new theoretical meaning here. Vosniadou and Brewer's (1992) concern about whether people could live upside-down in the southern hemisphere was not reflected in our tasks. The children had no difficulty in considering the southern hemisphere; we have, instead, shown their difficulty in considering the part of the Earth they do not see from their perspective.

Do our results support the mental model approach (Vosniadou & Brewer, 1992) or the fragmented knowledge approach (diSessa, 1988)? They did not confirm the existence of a coherent mental model constrained by presuppositions to which the child could systematically refer in response to a task. On the contrary, our observations are in line with the fragmented knowledge approach (diSessa, 1988; Nobes & Panagiotaki, 2007; Nobes et al., 2023; Siegal et al., 2004). Young children's knowledge seems to involve a gradual accumulation of fragments of cultural information that may be incompatible with each other and poorly integrated into a coherent whole. We have shown that the children mobilised one or more of these fragments of knowledge according to the demands of the task, and they changed fragments when moving from one task to another. Our observations further clarify this 'fragmentation'. We have shown that children mobilise fragments of knowledge from different sources, including astronomical knowledge (i.e., the Earth is spherical), geographical knowledge (i.e., the continents are distributed all over the Earth), and even episodic memory ('*I know that people live in the southern hemisphere because I have seen them on television*'). This explains why some children base their reasoning on a flat representation of the Earth or even on an Earth whose shape they do not care about in Task 2 and base their reasoning on a spherical Earth to solve Task 3. Some children's answers are mainly guided by geographical knowledge, while those of others are guided by the coordination of geographical knowledge and knowledge about the shape of the Earth.

Our observations also suggest that, although transitory, the choice of the knowledge to be mobilised seems to depend on the tasks previously performed. Of the eight children who succeeded in showing the shortest path through the Pacific from the first step, seven were questioned with the blank globe, and of the eleven children who had to be helped, ten were questioned with the regular globe. These contrasting performances can be explained by considering two processes. First, the presence and use of geographical knowledge in Task 2 inhibit the spontaneous mobilisation of a spherical representation of the Earth in Task 3. Second, once stimulated by locating the Pacific route on the globe, this representation of a spherical Earth becomes operative and allows children to succeed in Task 3. These results suggest: (I) children complete Task 2 without asking themselves about the shape of the Earth but by relying on the geographical information drawn on the globe; (2) the two types of knowledge are more or less easily mobilised: when they have the choice, children prefer to mobilise their geographical knowledge; (3) the two types of knowledge are not independent: the geographical knowledge is used as a support for mobilising a spherical representation of the Earth. For example, the presence of continents all around the Earth leads children to rotate the globe on its axis, which 'mechanically' leads to considering its sphericity. From a developmental point of view, the geographical knowledge acquired culturally and academically may serve as an anchor for a spherical representation of the Earth in space.

Limitations and implications

This exploratory study has limitations and opens up new research questions. Its main limitations are the relatively small number of children and its focus on a single age group. These options are justified by the exploratory nature of the study and its focus on the effect of the regular globe *versus* the blank-globe modality. Previous studies have shown that age is a determining variable in performance. A future study should, therefore, repeat this protocol in a developmental approach to analyse the evolution of performance and strategies, at least between the beginning and the end of elementary school.

Our research has pedagogical implications. The French curriculum tends to separate science classes in which the shape of the Earth is taught from an astronomical point of view and geography classes in which the shape of the Earth is taught from the point of view of the different elements that cover its surface. Our study shows that far from being independent, these two types of information are intertwined. Kampeza and Ravanis (2009) showed, from a geographical perspective, that linking geophysical features to a spherical surface improved children's representation of these geophysical concepts. Reciprocally, our study shows that the use of geographical features depicted on the globe contributes to the representation of a spherical Earth. These results encourage us to construct interdisciplinary activities that would allow children to acquire a more solid and operational representation of the Earth.

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