Concept of the Earth's shape in students 10 – 15 years old

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Abstract

The study used a forced-choice test (EARTH-2 test) that was presented to children (N=890) during the Covid-19 pandemic in the form of an online (web-based) survey. It was found that the use of a test adapted to an online survey led to fewer indications of near-scientific answers than when a paper-and-pencil test was used. Every third respondent (38%) inconsistently indicated a spherical Earth when explaining the location of people, trees, clouds, the movement of people and objects, and explained the phenomenon of day and night. In contrast, one in four 15-year-old students surveyed (27%) failed to indicate all the correct answers to the questions in the test.

Key words

Shape of the Earth, location of people, day-and-night phenomenon, EARHT-2 test, students 10-15 years

Résumé

L'étude a utilisé un test à choix forcé (test EARTH-2) qui a été présenté aux enfants (N = 890) pendant la pandémie de Covid-19 sous la forme d'une enquête en ligne (en ligne). Il a été constaté que l'utilisation d'un test adapté à une enquête en ligne conduisait à moins d'indications de réponses quasi scientifiques que lorsqu'un test papier-crayon était utilisé. Un répondant sur trois (38 %) a indiqué de manière incohérente une Terre sphérique lorsqu'il a expliqué l'emplacement des personnes, des arbres, des nuages, le mouvement des personnes et des objets, et a expliqué le phénomène du jour et de la nuit. En revanche, un élève de 15 ans sur quatre interrogé (27 %) n'a pas indiqué toutes les bonnes réponses aux questions du test.

Mots–Clés

Forme de la Terre, localisation des personnes, phénomène jour-nuit, test EARHT-2, élèves de 10 à 15 ans

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Introduction

Contemporary research studies in astronomy education can be divided into those that aim to (a) determine the level of children's astronomical knowledge (Blown & Bryce, 2020; Bryce & Blown, 2012; Frède, 2019; Güçhan Özgül, 2021; Kurnaz, 2012; Özsoy, 2012; Saçkes, 2015; Saçkes & al., 2016), (b) identify effective methods to help children construct astronomical knowledge (Baldy, 2023; Güçhan Özgül, 2021; Hannust & Kikas, 2012; Kampeza & Ravanis, 2012; Raviv & Dadon, 2020; Shaikh et al., 2020; Yalçınkaya-Önder et al., 2020), or (c) meta-analyse how children's knowledge of the universe is formed (Frède et al., 2011; Panagiotaki et al., 2006a; Siegal et al., 2004; Straatemeier et al., 2008; Vaiopoulou & Papageorgiou, 2018).

Research studies that consist in the diagnostic identification of children's astronomical knowledge involve three age groups. The first group of studies is conducted among younger preschoolers (usually from the age of 4) to determine at what age children begin to construct meaningful explanations of astronomical objects and phenomena (Blown & Bryce, 2020; Güçhan Özgül, 2021; Saçkes et al., 2016). The second group of studies is carried out among older preschoolers and younger school children (e.g., between 6 and 10) to determine how students' beliefs change under the influence of schooling (Bar et al., 2015; Bryce & Blown, 2012; Danaia & McKinnon, 2007). Finally, the third group of studies involves students over the age of 10 (Baldy, 2023). In this last group, studies can again be divided into those that include a small group of 10 and 11-year-old students in addition to studies of younger students (Baldy, 2023; Kikas, 1998; Mali & Howe, 1979; Schoultz et al., 2001; Vosniadou & Brewer, 1992, 1994) and those that focus on a cross-sectional determination of the astronomical knowledge of primary and secondary school students (from 10 to even 18 years old) (Bar et al., 2015; Baxter, 1989; Bryce & Blown, 2012; Danaia & McKinnon, 2007; Dunlop, 2000; Vosniadou et al., 2001). This paper is of a reporting nature and can be included in the last group of studies described here.

It is not uncommon for research studies to also involve adults, including teachers, to see how they affect students' knowledge (Cox et al., 2016; Ozkan & Akcay, 2016; Raviv & Dadon, 2020). These studies can be categorized as studies aimed at identifying effective methods to assist children in constructing astronomical knowledge. This is

because they not only look for techniques and tools to facilitate the transfer of knowledge but also establish the relationship between teachers' knowledge and the quality of verbal messages, as well as the cultural context (Baldy, 2023; Blown & Bryce, 2020; Bryce & Blown, 2012; Frède, 2019; Güçhan Özgül, 2021; Saçkes et al., 2016; Siegal et al., 2004). It is therefore not surprising that recently, studies of this type have often been conducted by comparing the knowledge of children from different countries, as well as checking and adapting research tools (Güçhan Özgül & Saçkes, 2015; Jelinek, 2020). This paper addresses the issue of psychometric equivalence between results obtained using a paper-and-pencil test and its online version.

In previous studies on children's understanding of basic astronomical objects and phenomena, it has repeatedly been shown that the quality of the results is determined by the tool used. It has been pointed out, among other things, that the use of tools with open and closed questions leads to differences in results (Panagiotaki et al., 2006b; Vosniadou & Brewer, 1992, 1994). It has been found that the use of a forced-choice test with closed questions (e.g., the EARTH-2 test) leads to more indications of scientific models than tools with open questions (Jelinek, 2021; Nobes et al., 2005; Panagiotaki et al., 2006b).

The tools used were often linked to a metacognitive discourse aiming to gain a deeper understanding of the nature of the knowledge structure constructed by children. The issues addressed included whether and to what extent students' knowledge is fragmented (*knowledge-as-element*) or coherent (*knowledge-as-theory*) (Frède et al., 2011; Jelinek, 2021; Saçkes et al., 2016; Vaiopoulou & Papageorgiou, 2018). Fragmentarists (Nobes et al., 2005; Panagiotaki et al., 2006a; Siegal et al., 2004; Straatemeier et al., 2008) assume that children who have the concept of a spherical Earth will indicate this shape when answering problem-based questions. The EARTH-2 test (Appendix 1), for instance, features problem-based questions about the location of people, plants, and atmospheric phenomena, how individuals and things move around the planet, and the phenomenon of day and night. The way in which these questions are answered will indicate to what extent a child has assimilated the concept of the Earth's shape into its knowledge structure. Answers included in the EARTH2 test (*EArth Representation Test for cHildren-2*) were based on mental models research by Vosniadou and Brewer (1992, 1994). Authors of the test (Straatemeier et al., 2008) designed the answers in such a way that each answer corresponded to one of the mental models (initial, synthetic or scientific). It was assumed that when a child solves the test, i.e., marks an answer in the form of a picture-symbol, it indicates one of these mental models. The authors believe that each of the problem-based questions in the test (questions about the location and movement of people and objects, as well as the phenomenon of day and night) can reveal to what extent the idea of the Earth's sphericity has been assimilated into the knowledge structure of the students studied. If a respondent marks the spherical shape of the Earth when answering questions about the location of people, trees and clouds,

but abandons the spherical shape of the Earth when answering questions explaining e.g., the day-and-night phenomenon, it suggests that the concept of the Earth's sphericity has only been assimilated in problem-based questions regarding location. When answering the remaining questions, the child reaches for a different image of the Earth's shape, e.g., flat, flattened or hollow Earth. In doing so, it proves that it is still using intuitive knowledge based on everyday experience (creating initial and synthetic models).

It is not entirely certain when the shape of the Earth - as a basic astronomical concept - is finally assimilated into the knowledge structure. Research among younger children indicates that even some 4-year-olds can already use this concept at a nearly scientific level. However, surveys of 10-year-old children indicate that many of them still use intuitions and conceptual outlines (initial and synthetic models) (Jelinek, 2021). It is certain that complete assimilation occurs as a result of solving a number of cognitive problems (Vosniadou & Brewer, 1992, 1994), and this in turn depends on many environmental factors.

Studies among older students (Blown & Bryce, 2020; Bryce & Blown, 2012; Danaia & McKinnon, 2007; Vosniadou et al., 2001) indicate that the number of children answering correctly to questions about the shape and size of planets, the apparent movement of the Sun in the sky, the day-and-night phenomenon, the movement of the Earth and the Moon around the Sun, the phases of the Moon and the seasons increases with age. At the same time, these studies indicate that not all older students provide nearly scientific answers, and the percentage of correct answers depends on the method used and the age of the group studied.

Some authors (Nobes et al., 2023; Nobes & Panagiotaki, 2007; Panagiotaki et al., 2009) claim that the reason why many adults gave unscientific answers was that they thought such simple questions must be a trick. Indeed, the answers given depended on the way the questions had been asked. However, I do not believe it is enough to say that the adults were looking for a "catch" in the question to explain the number of unscientific answers. The study analysed drawings and answers to open-ended questions that forced the respondents to formulate a full answer on their own. If the respondents had had a set of ready-made answers to choose from the test results might have been different. Such a set of answers would have clarified the context of the question. If the answers had been presented in the form of illustrations, then the perspective would also have been specified. Panagiotaki et al. established (Panagiotaki et al., 2006b) that if the answers are narrowed down, more science-like answers tend to be chosen. They found (2006b) that a tool with closed questions tends to provide a higher share of scientific responses. It can therefore be argued that this type of tool would provide a more truthful picture of the students' knowledge status.

This paper describes research studies using the EARTH-2 test which, although designed for 4 to 16-year-old respondents, had only been used to test younger children before (Güçhan Özgül, 2021; Straatemeier et al., 2008; Vaiopoulou & Papageorgiou,

2018). As it had not yet been used in studies of older students (over 10 years of age), its results point to a surprisingly low level of spherical Earth indications in all test questions in the 10-15 age group.

The decision to study older students as well was motivated by the surprisingly low knowledge level of Polish children between 5 and 10 years of age in the 2018 study (Jelinek, 2021). The results showed that only every second student at the end of the first educational stage (age 10) consistently cited the spherical nature of the Earth to explain the location of individuals and plants, the formation of clouds above the Earth's surface, the manner in which individuals and objects move on Earth, and the occurrences of day and night. The study revealed that 9- and 10-year-old students (N=103) encountered the greatest difficulties in explaining the phenomenon of nightfall (only 34% explained this phenomenon) and the movement of a ball kicked by a giant on the surface of the Earth (59.2% of third-graders answered correctly). The students were slightly better at explaining the location of trees (65.0%), the location of the Sun at night (75.7%) and the location of clouds above the Earth (79.6%). The location of people on Earth was correctly indicated by 79.6% of the respondents. The question of which received the most correct answers was the one concerning the movement of people on Earth (82.0%).

The poor astronomical knowledge of Polish students at the end of grade 3 seems to have been caused by the limited presence of astronomical contents and methods of astronomy education in the Polish educational system. In grades 1 to 3, education is integrated, which means that students learn about natural science in combination with language education, mathematics, visual arts, etc. From grade 4 to 8, students no longer receive integrated education, and teaching takes place in the form of specific subjects. However, astronomy education is not separated from other subjects. After the 2017 reform, astronomical subjects are discussed in *science* (in grade 4), *geography* (grades 5-8) and *physics* (grades 7 and 8) classes. Since Polish students only learn about gravity in the 6th grade, their knowledge of this phenomenon is lower than that of students in other countries [TIMSS-2019, https://timss2019.org/reports/ (Sitek, p. 20)]. It is relevant for the interpretation of the findings, as constructing an image of the Earth's shape in a near-scientific manner requires an adequate understanding of gravity (Bar et al., 1994, 2015; Mali & Howe, 1979; Nussbaum, 1979; Nussbaum & Novak, 1976; Vosniadou et al., 2001).

Materials and methods

The aim of the study was to determine how students in higher grades of primary school (grade 4 to 8) conceptualize the Earth, and how at this age (10 to 15 years) they incorporate this concept into their knowledge structure. It was aimed to determine how, in the context of the Earth's shape, they explain the location of people, trees, and clouds on the planet, how they represent the way people and objects move, and

how they explain the phenomenon of nightfall on the Earth. The study to determine how older students conceptualize the Earth was conducted from November 2020 to May 2021. In Poland and other countries, there was a Covid-19 outbreak. Schools were closed due to sanitary restrictions. Thus, when designing the research method, it was not possible to apply direct research methods, i.e., an interview or even the traditional paper-and-pencil test. This left the researchers with electronic means of communication.

To compare the results with previous studies (Jelinek, 2021), it was decided to use the same tool, the EARTH-2 test. This tool had been developed based on mental models of the Earth's shape as identified by Vosniadou and Brewer (1992, 1994), the presence of which was confirmed among Polish children in separate studies (Jelinek, 2020).

Assured that the test had no cultural constraints, we proceeded to prepare an electronic version of the test for use under the sanitary regime. The test has been brought to the Google Forms platform, maintaining the order of the questions and graphical layout of the original booklet. When the electronic version of the test was being developed, the question arose whether students should be able to access all the test questions all the time, or whether the questions should appear on the screen one by one. It was decided that while completing the test, the students would have access to all the questions. The reason for not choosing to restrict access to the test questions was that during the paper-and-pencil test, students were also able to view all the questions in the booklet at any time.

Volunteers (university students) had been invited to carry out the tests. Ten volunteers applied and were trained to contact educational institutions, send out the tests and collect the research data. The volunteers asked the following groups for permission to conduct the research: school headmasters, teachers, and parents (in that order). After permission had been granted, teachers informed their students about the study and sent them a link to the EARTH-2 test asking them to complete it. Then, test sheets sent back by the volunteers were automatically collected on the Google Forms platform (appendix 2), from which they were downloaded as an Excel sheet for further analysis. The file was later uploaded to the Figshare platform (http://doi.org/10.6084/m9.figshare.17213522).

Respondents were guaranteed anonymity during data collection. In respondent's particulars, we only asked about gender, place of residence (rural/urban), age and grade. During preliminary analysis, we removed the forms in which the particulars contained false information (e.g., age: 99).

Eventually, a total of 890 forms were analyzed. They had been filled in by fourth- to eighth graders, i.e., children between the ages of 10 and 15. The results of the test will be presented separately for three age groups: 10- and 11-year-olds (356 students), 12- and 13-year-olds (279 students), and 14- and 15-year-olds (255 students). The average age of the respondents was 12.22. The studied group consisted of 478 females and 412 males, 365 of them lived in the countryside and 525 in a city.

RESULTS

An overall analysis of the results (Appendix 3) shows that, depending on the question, scientific models are indicated by between 65% and 93% of the students surveyed. The highest level of scientific model indications was determined for the question directly related to the shape of the Earth (93%). In contrast, the lowest level of scientific model indications related to the phenomenon of nightfall (65%) and the movement of a ball on the planet's surface (66%). These difficulties prove that many of the students surveyed have not yet assimilated a fully formed concept of the shape of the Earth into the knowledge structure.

In the remainder of this paper, the findings will be presented on two levels of analysis. The first level will deal with the consistency of mental model indications in all test questions (initial, synthetic or scientific). This analysis will be carried out in relation to the variables of age, gender, and place of residence.

The second level of analysis will focus on trends of scientific model indications in different age groups. This analysis will identify the extent to which respondents adhered to the spherical shape of the Earth in age groups 10-11, 12-13 and 14-15, and thus identify with which cognitive problems children in these age groups still struggle.

Analysis of consistent mental model indications in all test questions

Some questions in the EARTH-2 test can be described as control questions because, in terms of the subject-matter, they refer to similar problems as questions that have already been asked but present the problem in a slightly different way. For example, both questions 1 and 8 ask about the shape of the Earth. Question 1 is *What does the Earth look like?,* and question 8: *Which picture resembles the Earth best?* The authors of the test assume that, answering indirect questions (2-7), students solve several cognitive issues related to the shape of the Earth and so, when proceeding to question 8, they may give a different answer than in question 1. Thus, a comparison of answers to questions 1 and 8 makes it possible to determine whether students remain consistent when answering questions about the shape of the Earth. Furthermore, acquiring knowledge regarding a child's consistent selection of the Earth can aid in comprehending whether students adhere to the same mental model of the Earth's shape when addressing all problem-based inquiries, as posited by Stella Vosniadou (2004) in her concept of *knowledge as theory*.

Table 1 presents the absolute number as well as percentage of indications for each model (illustrations). The first column gives the number and percentage of students who indicated relevant image in question 1 (cf. Appendix 3). The second column, however, presents the number and percentage of students who indicated the same mental model in questions 1 and 8. Based on the second column, the authors were able to measure consistency of the answers.

A comparison of question 1 and question 8 showed that 93% (Table 1) of respondents were consistent in selecting the models. Among these students, 90% indicated the scientific model (Earth as a sphere), and the remaining 3% of students selected the synthetic model and the initial model. 7% of the students surveyed changed their choice of Earth's shape between questions 1 and 8.

TABLE 1

The consistency of choosing the same image in (Q1) What does the Earth look like? and (Q8) Which picture resembles the Earth best?

Q1	N=890	Q8	N=890
	817 91.80%		797 89.55%
	5 0.56%		2 0.22%
	31 3.48%		13 1.46%
	29 3.25%		13 1.46%
	8 0.90%		3 0.34%

As regards the remaining questions of the EARTH2 test (2-7 and 9), two answers representing the Earth as a sphere predominated. In order to analyze the respondentss consistency in selecting pictures-symbols representing a spherical Earth, we had to consider both those answers. In addition to the scientific model, there was also a synthetic model in which, for example, people and trees were depicted at the top of a spherical Earth (the so called *no gravity model*). The list of answers to the test about both wordings of the question is presented in Table 2. It shows how students gradually moved away from pointing to the Earth as a sphere, i.e. were inconsistent in their answers.

TABLE 2

Number and percentage of answers of students who indicated and abandoned the indication of the spherical shape of the Earth

Test questions	Number of answers representing a spherical Earth (number of question in the test)	Number of students who selected a spherical Earth	Number of students who indicated a different shape of the Earth
1. What does the Earth look like?	1 (5)	817 91.80%	73 8.20%
2. Which picture shows best where the people live on the Earth?	2 (1,4)	767 86.18%	123 13.82%
3. Which picture shows best where he clouds are?	2 (1,2)	727 81.69%	163 18.31%
4. Which picture shows best what happens when a giant kicks a ball real hard?	2 (3,6)	653 73.37%	237 26.63%
5. Which picture shows best where the trees are on the Earth?	2 (2,4)	636 71.46%	254 28.54%
6. Where is the Sun at night?	2 (2,5)	620 69.66%	270 30.34%
7. What happens when you walk along a straight line for a very long time?	2 (1,3)	580 65.17%	310 34.83%
8. Which picture resembles the Earth best?	1 (4)	577 64.83%	313 35.17%
9. Which picture shows best how night falls?	2 (1,5)	554 62.25%	336 37.75%

The number of students who consistently adhered to the spherical shape of the Earth dropped from 92% in question one to 62% in question nine. The 554 respondents who indicated a spherical Earth in all questions included:

- 214 children aged 10 and 11 years, representing 60.11% of all respondents at that age;
- 173 children aged 12 and 13 years, representing 62.01% of all respondents at that age;
- 167 children aged 14 and 15 years, representing 65.49% of all respondents at that age.

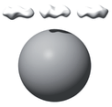
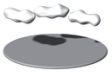
It is evident from the results of the test that students have not yet fully assimilated the concept of the Earth's sphericity into their conceptual structure. In most cases, with each

following question, about 2 to 5% of the respondents abandoned their initial answer, but the highest number (over 8%) of deviations from the spherical shape of the Earth occurred in question 4 about the behaviour of a kicked ball compared to question 3. This proves that it is easier for respondents to understand the phenomenon of gravity when asked about the location of people, trees and clouds, or even the movement of people on Earth, i.e., phenomena they can observe daily. However, it is more difficult in the case of a moving object (such as a ball) and the phenomena of day and night.

To analyse references to the location of people, clouds and trees, we will compile answers given by students to questions 2. *Which picture shows best where the people live on the Earth?*, 3. *Which picture shows best where the clouds are?* and 5. *Which picture shows best where the trees are on the Earth?* (Table 3).

TABLE 3

Consistency of mental model selection in questions: (Q2) Which picture shows best where the people live on the Earth? (Q3) Which picture shows best where the clouds are? and (Q5) Which picture shows best where the trees are on the Earth?

Q2	N=890	Q3	N=725	Q5	N=666
	717 80.56%		651 73.15%		606 68.09%
	88 9.89%		21 2.35%		16 1.80%
	6 0.67%		2 0.22%		0
	52 5.84%		35 3.39%		30 3.37%
	27 3.03%		16 1.80%		14 1.57%

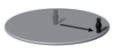
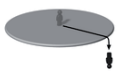
An analysis of the consistency of answers to the three questions (2, 3 and 5) shows that among 890 students surveyed, one in four (25%) showed inconsistency by indicating different models in consecutive test questions. The majority of the remaining stu-

dents selected the scientific model (68%), followed by synthetic models (5%) and the initial model (2%). Deviations from the scientific model in subsequent questions were gradual (7% and 5% respectively). The higher percentage of deviations from synthetic models (8% for the model in which people, clouds, and trees are at the top and above the surface of the planet) indicates that respondents don't consider the explanations presented in the pictures-symbols to be definitive, certain, and, consequently, are willing to alter their responses.

By comparing question 2 *Which picture shows best where the people live on the Earth?* and question 7 *What happens when you walk along a straight line for a very long time?* it will be possible to determine how secondary school students explain the location and movement of people on Earth (by pointing to a picture-symbol) (Table 4).

TABLE 4

Consistent selection of the same models in questions: (Q2) Which picture shows best where the people live on the Earth? and (Q7) What happens when you walk along a straight line for a very long time?

Q2	N=890	Q7	N=890
	717 80.56%		615 69.10%
	88 9.89%		3 0.34%
	6 0.67%		0
	52 5.84%		27 3.03%
	27 3.03%		12 1.35%
			4 0.45%

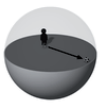
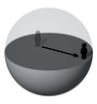
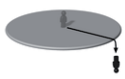
Data analysis shows that almost 70% of the respondents were consistent in selecting the scientific model. By indicating the scientific model, they acknowledged that human beings

can live on each side of the planet and move all over its surface. Among respondents who pointed to synthetic models, only 3% were consistent (16.4% indications in question 2). This proves that synthetic models are a temporary explanation for those students surveyed who are unsure about the phenomenon. Low consistency in the case of synthetic models proves that a process of continuous formation of the concept of the Earth's sphericity is in place (assimilation of the concept into the structure of knowledge).

A similar effect, i.e. a high number of deviations from synthetic models, was also observed when we analysed consistency of answers to questions 4 *Which picture shows best what happens when a giant kicks a ball really hard?* and 7 *What happens when you walk along a straight line for a very long time?* Details of the relationship between questions 4 and 7 are presented in Table 5.

TABLE 5

Consistency of indications in questions: (Q4) Which picture shows best what happens when a giant kicks a ball real hard? and (Q7) What happens when you walk along a straight line for a very long time?

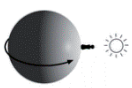
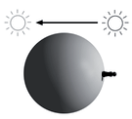
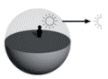
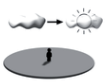
Q4	N=890	Q7	N=890
	590 66.29%		547 61.46%
	135 15.17%		13 1.46%
	17 1.91%		1 0.11%
	78 8.76%		45 5.06%
	56 6.29%		22 2.47%
	14 1.57%		6 0.67%

The difference of almost 5% in scientific model selection in questions 4 and 7 indicates that the majority of students surveyed conceptualize the movement of a kicked ball and people walking on the surface of the Earth similarly. Whereas, an analysis of synthetic model indications shows that these models are not permanent in the answers of students. In response to question 4, 26% of the respondents indicated synthetic models, while in question 5, these models were indicated by almost 7% (19% less). The high percentage of synthetic models selections in question 4 proves that, when answering how a ball would behave, the respondents most often referred to everyday experience (a ball kicked on a flat Earth). The indications of initial models seem to prove that the students surveyed had great difficulty in explaining these phenomena on a planetary scale.

The EARTH2 test addresses the day and night cycle in questions 6. Where is the Sun at night? and 9. Which picture shows best how night falls? An analysis of consistency of indications of the same models (pictures-symbols) will make it possible to ascertain whether students are consistent in explaining the day and night phenomenon. A detailed distribution of answers to these two questions is presented in Table 6.

TABLE 6

Consistency of answers to questions: (Q6) Where is the Sun at night? and (Q9) Which picture shows best how night falls?

Q6	N=890	Q9	N=890
	718 80.67%		514 57.75%
	90 10.11%		28 3.15%
	31 3.48%		16 1.80%
	39 4.38%		21 2.36%
	12 1.35%		4 0.45%

An analysis of scientific model selections in questions 6 and 9 showed that only 58% of respondents correctly marked the picture representing the scientific explanation of the day and night phenomenon. In both questions, synthetic models were selected by only 5% of respondents and initial models by less than 3%. Less than 60% of scientific model indications was the lowest result in the whole survey. It proves that the phenomenon of day and night poses a major difficulty for the students surveyed. Even though 80% of respondents were able to locate the Sun at night, 23% fewer children could point to a picture showing the rotation of the Earth. An analysis of answers to the question about nightfall only showed that as many as 21% of respondents pointed to the model of the apparent movement of the Sun in the sky. This proves a strong influence of personal experience in explaining the day and night cycle among older primary school students.

Trends in terms of scientific model selection in different age groups

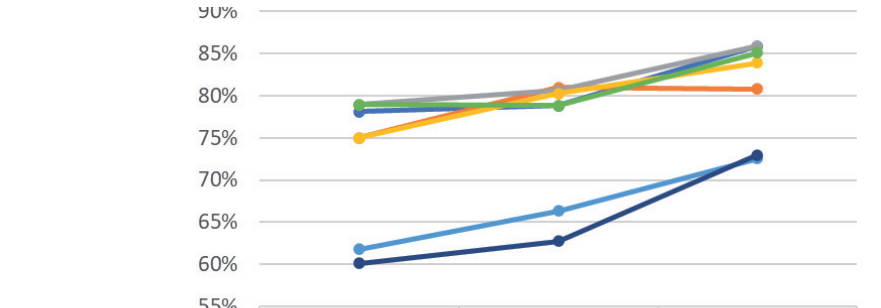
Throughout all age groups, there are two questions (cognitive problems) which pose the greatest difficulties for the students. It is the question about the movement of a kicked ball (question 4) and the question about nightfall (question 9) cf. Appendix 3. The number of correct answers to both questions increases with age. In the age group 10-11, correct answers were indicated by 60-62%, in the age group 12-13 it was 63-66%, and in the age group 14-15 it was 72% respectively. There is also a significant difference in the answers to the other questions in the test (about the shape of the Earth and the location of trees, clouds, and people). The percentage of scientific model indications in these questions amounted to 75-79% among 10 and 11-year-olds, 79-81% among 12 and 13-year-olds and 81-86% among 14 and 15-year-olds. Detailed data on the percentage of scientific model indications is presented in Figure 1.

In an analysis considering only indications of illustrations corresponding to scientific models, it was found that the number of students who consistently chose this one across all test questions increased with age. In the age group of 10- and 11-year-olds tested, there were 32% such students, in the group of 12- and 13-year-olds there were 35%, and in the group of 14- and 15-year-olds there were 42%. Similarly, the number of students indicating non-scientific models (preliminary and synthetic) decreases with age.

Gender and knowledge of astronomy among the students surveyed. The study included 478 female and 412 male participants. The highest difference in indications of scientific models between male and female respondents was 6.7%. Apart from the question directly related to the shape of the Earth (questions 1 and 8), women indicated synthetic models slightly more often. In contrast, men gave more indications of initial models presenting the Earth as a disc. The difference in this respect reached 4% at most (in the question about the location of clouds). An exception among the indications of initial

models were the questions about the movement of people on Earth and the phenomenon of nightfall. Women indicated initial moment 4% more often. It was concluded that differences in indications of scientific, synthetic and initial models between women and men were similar.

FIGURE 1C



	Age 10 and 11	Age 12 and 13	Age 14 and 15
Location people	78,1%	78,9%	85,9%
Location tree	75,0%	81,0%	80,8%
Location clouds	78,9%	80,7%	85,9%
Moving people	75,0%	80,3%	83,9%
Moving bal	61,8%	66,3%	72,6%
Location Sun at night	78,9%	78,9%	85,1%
Night falls	60,1%	62,7%	72,9%

Percentage of scientific model indications for all test questions among students surveyed

Place of residence and knowledge of astronomy among the students surveyed. Let us recall that of the students surveyed, 365 lived in rural areas and 525 in urban areas. The authors asked students where they lived because in cities the night sky is highly illuminated. This makes it more difficult to observe celestial bodies, and thus may lead to differences in the astronomical knowledge of older schoolchildren. In terms of scientific model selection, differences between both groups of students ranged from 0.03% (in question about the shape of the Earth) to 7.3% (in question about nightfall) and favoured students who lived in cities. There was one exception, the question about the movement of people on the Earth's surface, to which more children from rural areas answered correctly. However, even then, the difference in terms of scientific model indications was only 2%. The extent of differences between urban and rural students in terms of scientific model indications turned out to be small.

Conclusion and discussion

Age and knowledge of astronomy among the students surveyed. The results showed a relatively certain consistency of indications of a spherical shape of the Earth in all test questions. Among all students, 62% indicated a spherical shape of the Earth, regardless of any scientific model, while 65% of the students in the 14 - 15 age group were also indicating this. This also means that one in three respondents showed inconsistency in indicating the shape of the Earth when answering the question about the position of people, trees, clouds, the movement of people and objects and explaining the phenomenon of day and night.

The study also indicated that the number of scientific model indications (i.e. indications of an illustration corresponding with the scientific model) increases with age, and that there is a steady decrease in the number of indications of initial and synthetic models for all questions in the test. The biggest surge in indications of scientific models between 10 and 11-year-olds and 14 and 15-year-olds relates to the question about nightfall (12% difference) and the movement of a kicked ball (11%). The remaining differences range from 5 to 8%. These two issues (nightfall and ball movement) presented the respondents with a considerable difficulty in each age group. The number of correct answers to these two questions in all age groups was 15% lower than the answers to other questions in the test. This means that these two problems still pose cognitive problems for the students surveyed (10-15 year olds). The seriousness of this issue is evidenced by the fact that as many as one in four surveyed secondary school-leavers did not indicate all the correct answers to the questions in the test.

The reason students had such great difficulty in explaining how a kicked ball moves is that they have little knowledge of the phenomenon of gravity. In Polish schools, this phenomenon is not discussed in the first four years of primary school. Younger students surveyed solved this task based on their intuitive understanding of natural phenomena, whereas older students who had already discussed basic information on gravity in school were able to provide answers in a more scientific manner. The same is true for explaining the phenomenon of nightfall. Polish schools rarely conduct experiments that would allow children to observe the behaviour of celestial bodies in the form of models. Students learn about these issues from textbooks. In consequence, abstract phenomena are not clear to children, and they rely on their personal experience to explain them.

As no studies using the EARTH2 test have been conducted among students above 10 years of age, it is not possible to carry out a detailed comparative analysis of the results obtained. Studies that involved other tools [e.g. Astronomy Diagnostic Test (Danaia & McKinnon, 2007)] referred to a different range of questions. Nevertheless, it is clear from this study that older students do not have complete scientific knowledge. The study indicates that many 15-year-olds who finish secondary school have not learned about the Earth's shape yet. Consequently, they do not refer to it to explain how a ball moves or how night falls.

Since studies conducted among adults (Cox et al., 2016; Ozkan & Akcay, 2016; Raviv & Dadon, 2020) also show that some respondents have not grasped these concepts, a more general question arises. Do some people never fully assimilate the concept of the Earth's shape into the knowledge structure? So far, it has not been possible to give a clear answer to this question. A comprehensive research analyses would be required.

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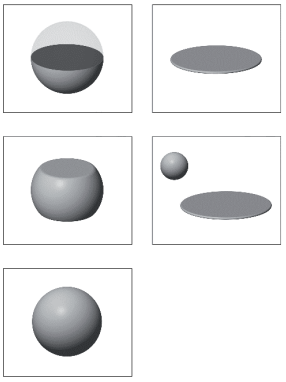
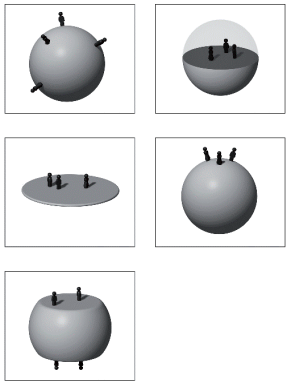
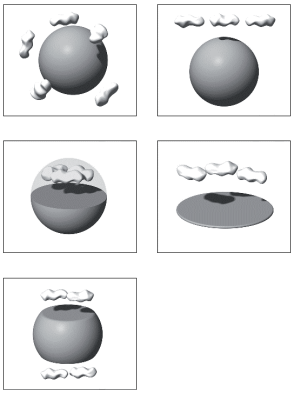
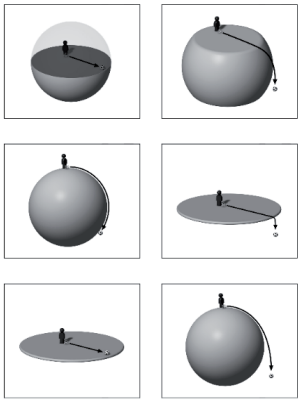
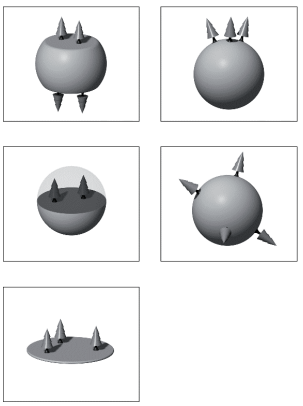
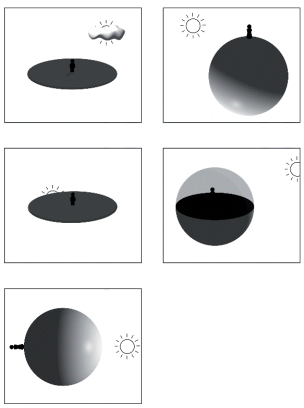
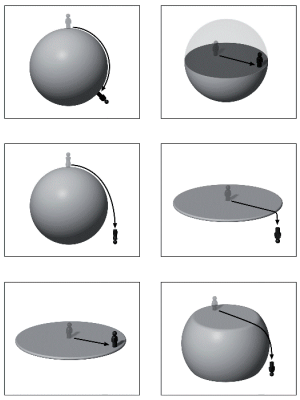
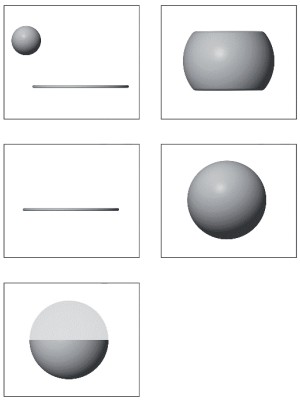
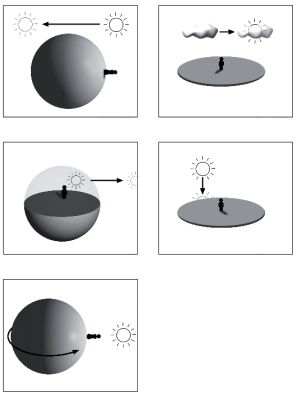
Appendix I

In presenting the following questions, the trial question 'mark the cat' was omitted; this question was available in the original and online versions.

Table app. 1

Test EArth Representation Test for cHildren, version 2 (EARTH2)

1. What does the earth look like?	2. Which picture shows best where the people live on the earth?	3. Which picture shows best where the clouds are?
		
4. Which picture shows best what happens when a giant kicks a ball real hard?	5. Which picture shows best where the trees are on the earth?	6. Where is the sun at night?
		

7. What happens when you walk along a straight line for a very long time?	8. Which picture resembles the earth best?	9. Which picture shows best how night falls?
		

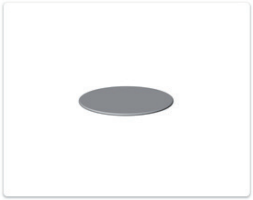
Appendix 2

Table app. 2

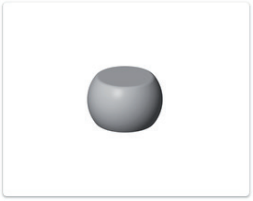
The first question of the EARTH2 test placed on the Google Forms platform and an example of moving from one question to another (scrolling)

1. What does the earth look like? *

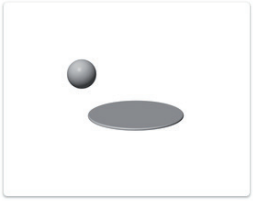
Option 1



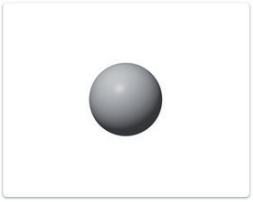
Option 2



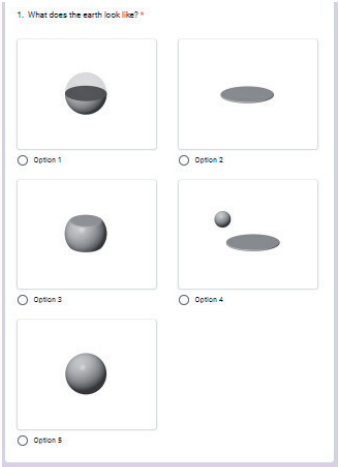
Option 3

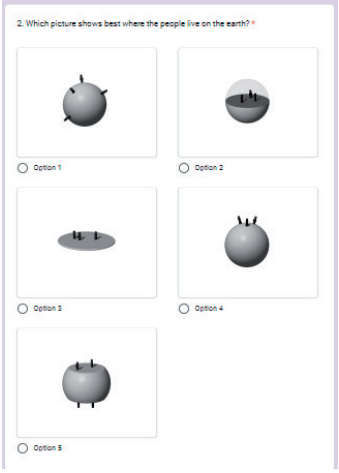


Option 4



Option 5





APPENDIX 3

TABLE APP. 3

Distribution of indications into mental models

	Mental Models						
	Flat Earth		Hollow	Dual	Flattened	No gravity	Scientific
1. What does the Earth look like?	8 0.90%		29 3.25%	5 0.56%	31 3.48%	-	817 91.80%
2. Which picture shows best where the people live on the Earth?	27 3.03%		52 5.84%	-	6 0.67%	88 9.89%	717 80.56%
3. Which picture shows best where the clouds are?	26 2.92%		71 7.98%	-	6 0.67%	62 6.97%	725 81.46%
4. Which picture shows best what happens when a giant kicks a ball real hard?	Falls off the Earth 14 1.57%	Does not fall off the Earth 56 6.29%	78 8.76%	-	17 1.91%	135 15.17%	590 66.29%
5. Which picture shows best where the trees are on the Earth?	43 4.83%		54 6.07%	-	4 0.45%	90 10.11%	699 78.54%
6. Where is the Sun at night?	Cloud 39 4.38%	Sundown 12 1.35%	31 3.48%	-	-	90 10.11%	718 80.67%
7. What happens when you walk along a straight line for a very long time?	Falls off the Earth 12 1.35%	Does not fall off the Earth 50 5.62%	75 8.43%	-	22 2.47%	26 2.92%	705 79.21%
8. Which picture resembles the Earth best?	11 1.24%		24 2.70%	11 1.24%	17 1.91%	-	827 92.92%
9. Which picture shows best how night falls?	Cloud 15 1.69%	Sundown 80 8.99%	30 3.37%	-	-	190 21.35%	575 64.61%