

Article

From the Spherical Earth Model to the Globe: The Effectiveness of a Planetary Model-Building Intervention

Jan Amos Jelinek 

Institute of Human Development Support and Education, The Maria Grzegorzewska University,
02-353 Warsaw, Poland; jajelinek@aps.edu.pl

Abstract: The shape of the Earth is a fundamental concept that students need to learn in astronomy education. This paper reports the findings of a study that confirms the effectiveness of an intervention involving the construction of a model of the Earth prior to the introduction of the globe as a codified artefact. The educational intervention had been preceded by the EARTH2 test, which was used to check how well students participating in the study mastered the concept of the Earth's shape. The study included forty-seven primary school students (grades I and II). Effectiveness was measured by comparing the answers chosen by Polish children in a test as mental models. The study confirmed (A) that the intervention was effective: 49% of progressive changes, 30% of regressive changes, and 21% of changes within the same mental model were observed; (B) that there was an increase in the children's interest in space, revealed by an increased number of questions going far beyond the school astronomy curriculum; and (C) that students' concerns about the dangers of space were revealed. Key findings include the following: (a) Educational effectiveness regarding the concept of the shape of the Earth is achieved in activities that involve building a spherical Earth model before introducing a globe as a ready-made model. (b) The topics addressed in astronomy classes must be far broader than what the current curricula provide. They should take into account current issues reported by the media and deal with astronomical discoveries and space technology. (c) When organising activities, children's concerns about the dangers of space should be borne in mind.

Keywords: astronomy; Earth's shape; educational intervention; effectiveness; EARTH2 test



Citation: Jelinek, J.A. From the Spherical Earth Model to the Globe: The Effectiveness of a Planetary Model-Building Intervention. *Educ. Sci.* **2024**, *14*, 761. <https://doi.org/10.3390/educsci14070761>

Academic Editors: Alice Delserieys
Pedregosa and Maria Kampeza

Received: 22 May 2024
Revised: 5 July 2024
Accepted: 9 July 2024
Published: 12 July 2024



Copyright: © 2024 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

When viewed in everyday life, the Earth appears flat. This impression has an enormous impact on the formation of the Earth's shape concept [1,2]. Since children are confronted with this image from the beginning of their lives, it becomes strongly embedded in their psyche, and they resort to it to explain natural phenomena [3,4]. The concept of the Earth's shape has a strong influence on the development of higher astronomical concepts, such as the day-and-night phenomenon [5,6]. Such concepts are referred to as threshold concepts because they are the gateway to a deeper understanding of science [7].

Research shows that it takes a long time before children start applying the concept of a spherical Earth to explain cosmic phenomena [8]. Such a long persistence of a misconception regarding the Earth is influenced, among other things, by cultural factors [9]. Appropriate educational support, on the other hand, causes children to adopt a spherical image of the Earth earlier. The effectiveness of educational interventions is confirmed as early as preschool [10–17].

Educational effectiveness is measured by establishing the difference between children's prior knowledge and their knowledge after the intervention. In the case of threshold concepts [7] (such as the Earth's shape concept), which serve as a lens for explaining natural phenomena [18], it is the degree to which a particular concept is embedded in a child's conceptual structure that can serve as a measure of educational effectiveness. The degree to which a concept is embedded in said structure can be established by checking whether the

child applies the concept to explain natural phenomena. At the lowest level of grasping a concept, i.e., when integration in the structure is poor, a child simply replicates the response pattern. This is revealed when, when asked directly *what shape the Earth is*, the child directly answers *spherical*. However, when asked to explain other phenomena, they no longer refer to the Earth as a sphere. A higher degree of the concept's integration in the knowledge structure (also referred to as structuring) is revealed by those children who constantly refer to the spherical Earth when solving problems (e.g., in order to answer how people move on Earth). This issue is crucial when we talk about the contextualised use of the concept.

When examining the degree of structuring, we find that even many older students (10 years old) do not have a well-embedded concept of a spherical Earth [19]. To explain natural phenomena (the location and movement of people, the location of trees and clouds, the movement of a kicked ball, and the location of the sun at night), they abandon the concept of a spherical Earth. If the concept of a spherical Earth is not properly embedded, it can lead to difficulties in adopting more advanced astronomical concepts, such as the phenomenon of day and night [20–22]. For this reason, it is suggested that the concept of the Earth's shape should be supported at the beginning of the educational path [16].

This assumption is employed in the Polish preschool education and early school education systems. Despite these assumptions, the scope of science education (including astronomy) is severely limited. At the level of preschool education, children learn about the phenomena of day and night, the seasons, the phases of the Moon, and the Polish astronomer Nicolaus Copernicus. In the early grades of primary school (I–III), these contents of astronomy education are repeated. The concept of the Earth's shape, despite being a key concept [7], is only marginally present in the Polish education system. Teachers devote too little time to explaining the image of the spherical planet to children. Currently, the curriculum is being re-examined, and efforts are being made to modify it [19].

Forming the notion of a spherical Earth is difficult because it requires one to accept information that contradicts everyday observations. Hence, appropriate intervention is key [2,11–13,15,16,23]. Research shows that a teacher who introduces a globe to children without any prior explanation does not achieve the intended goal [4]. Children who are convinced that the Earth is flat have difficulty accepting a globe as a cosmological model of the Earth.

Research into the development of the Earth's shape concept suggests that a significant change in the conceptual structure is required. Such a change is referred to as reconstruction (accommodation, [24]), and it causes one to explain phenomena through a new lens (frame, [18,22,25–27]). When the spherical shape of the Earth is assimilated, it also forces a change in perceptions as to the location of people living on Earth and the way they move. Indeed, in their everyday experience, children live their lives “on a flat Earth”. Accepting the notion that the Earth is a sphere forces them to address the question of whether people can live on the curvature of the planet and whether they can live on the other side of it. The same is true of the phenomenon of people moving across the sphere. These questions do not arise spontaneously but are the result of deeper reflection and do not necessarily reveal themselves in all children [3,9]. The realisation that people walking for days in one direction would arrive at the place where they started (a characteristic of the sphere) and that they would not fall off the Earth (gravity) is a nearly scientific explanation that requires a change in perspective and proper knowledge.

Conceptual change, broadly speaking, involves the gradual transfer of objects and phenomena visible on a daily basis, from a “flat” Earth to a “spherical” one. This mental “relocation” is a way of solving cognitive problems [2,19]. The shift is possible once the right information has been acquired and the right level of cognitive skills has been achieved to construct the right ideas [18,23]. Similarly, the phenomenon is elucidated by proponents of the precursor model theory [25]. They contend that for a child to comprehend a phenomenon, it is essential to construct appropriate cognitive frameworks [26]. The specific type of cognitive development required for a child to understand the Earth's spherical shape involves (a) recognising that the ground observed daily is part of a larger whole

and (b) understanding that viewing the entire Earth necessitates a change in perspective (significant distancing from its surface).

1.1. Development of the Earth's Shape Concept

The process of integrating the Earth's shape concept into one's mental structure is described by the mental models theory by Stella Vosniadou and William Brewer [3,27]. The concept of mental models implies that children construct coherent ways of explaining phenomena. Ranging from initial models through synthetic models to scientific models, they chart a developmental pathway [19]. Regarding the Earth's shape, mental models are usually invoked in the context of secondary problems, such as the location and movement of people on Earth. Children coherently reveal their beliefs through statements, drawings, and plasticine creations. Due to their coherent nature, well-structured childlike logic, and their explanatory and predictive nature, such statements are considered to be close to theories. Initially, children locate people on a flat Earth [3,28]. In their drawings, they depict the Earth as a line of infinite length with the ground beneath it and draw people standing on that line. From the children's explanations and opinions, it appears that they are recounting a personal experience, i.e., the sight of people walking on the Earth. When given a lump of plasticine, they form a cuboid and stick human figurines in it as if they were standing on the Earth [19,29].

Children in whom the process of constructing the notion of a spherical Earth has already begun start explaining that people only live at the top of the planet and add that they cannot go any lower because they would fall off the Earth [3,30]. However, the imaginary edge of the Earth is not necessarily physical. In their explanations, they refer to psychological barriers, such as speaking another language [29]. Sometimes they further flatten the part of the sphere where people live [28]. On a piece of paper, they draw a circle representing the part of the Earth where people live seen from above. Using plasticine, they make a sphere, flatten it on one side, and stick a figurine there to mark the location of people [19].

Sometimes, when constructing the concept of sphericity, children explain that people live inside a hollow Earth (*hollow sphere model*, [3]). This representation confirms the spherical shape of the Earth and agrees with the statement that it is impossible to fall from the Earth (people are surrounded by Earth on all sides). They draw a circle on a piece of paper and locate people inside at the bottom of the circle. With a lump of plasticine, they try to create a sphere and, pointing to a hole, explain that people live inside it.

There are also children who depict two types of Earth in their drawings—one spherical and the other flat. They explain that the flat one represents what they see every day, while the other refers to what the teacher says when showing a globe (*dual Earth model*, [3]). Similar behaviour is observed in studies using plasticine. After building a globe, children claim that it is the Earth but different from the one they live on [29].

The development of the Earth's shape concept is linked to the concept of the location of clouds and the direction of rainfall. Research shows that before children adopt the idea that the clouds are located around the spherical Earth, they place them just above the flat Earth [3]. In drawings, they mark their location parallel to the line of the ground. As they start imagining the Earth as a sphere, they explain that clouds—like people—are only located at the top. The direction of rainfall seemed to correspond with their ideas about the direction of gravity.

1.2. Effective Structure of Interventions

Research on the effectiveness of educational interventions in changing children's beliefs about the shape of the Earth shows that they can be effective as early as preschool. A study of Greek children by Maria Kampeza and Konstantinos Ravanis [2] indicated that even a two-day educational activity that allowed children to experience the shape of the Earth can influence the formation of children's perceptions. The authors concluded that, already, preschool children are ready to accept the scientific idea of the shape of the Earth

if only the activities are organised in an appropriate way. Based on the precursor model, they hypothesised that by understanding children's learning processes and cognitive development, it is possible to design appropriate activities during which engaged children would discover changes and, guided by the teacher, formulate conclusions similar to scientific ones [25,31–33].

The effectiveness of the intervention was confirmed in those activities where children were appropriately engaged in conversation [34], children were allowed to express their opinions and confront them with each other [35], a globe and plasticine balls were used to simulate cosmic phenomena [15], inquiry-based games were used [11], multimedia programmes were used [23], there was regular switching between the map and globe [36], and geographical characteristics were taken into account [2,10]. Previous research focused on establishing the effectiveness of single forms of educational interventions. This paper presents the results of a study in which most of these forms were used: conversations and discussions, building a model of a spherical Earth and using it in simulations, and supplementing the resulting experience by watching computer animations.

Studies have shown that without a proper introduction and the right sequence, the educational materials may even hinder the learning process [4]; moreover, they may promote the development of non-scientific concepts [21]. For this reason, the present study focused on analysing a structure of interventions that would maximally support children in forming the concept of a spherical Earth. Children's visuo-spatial reasoning abilities were adopted as a starting point, which may be particularly important in the formation of astronomical concepts [23]. The author invoked the concept of Nikolai N. Poddyakov [37], who explains how to support children in their transition from concrete-motor thinking, which requires performing operations on objects, to concrete-pictorial thinking allowing the use of operations in the mind. Due to the lack of an English translation of the publication, the following paragraph presents the essence of Poddyakov's explanation as it was published in Polish [37].

As children develop concrete-pictorial thinking, actions previously performed on real objects begin to be reproduced in the imaginary plane without the help of actual objects. A particular detachment of actions from reality takes place. It is more effective when it does not occur immediately, but goes through intermediate stages, i.e., a child reproduces these actions not on real objects, but on substitute objects, i.e., models. Initially, the model may appear as an exact copy of the object. Then, too, fundamental changes in the child's activity are already taking place. The child operates on the model of the object and, with the help of an adult, comes to an understanding of what a model is, compares the actions performed on it with the original. In other words, children realise quite quickly that their actions relate to the original, although they are performed on the model. This is a crucial moment in the formation of pictorial thinking, in which models and actions performed on them play an important role.

Poddyakov's concept, briefly presented here, indicates that when teaching children about the shape of the Earth, one should construct a model of the planet before introducing a globe. According to Poddyakov, by operating on such a model, children will more easily assimilate the phenomena associated with the Earth model. It was recognised that for astronomical topics, the application of Poddyakov's didactic model has practical relevance within the precursor model concept, which has traditionally been used to explain physical phenomena [25].

The starting point for organising effective learning situations according to the precursor model is to have a good understanding of the children's learning process [31,33]. The way children learn and the changes that occur in the way they think are already known. Therefore, appropriate activities can be prepared. Poddyakov hints that by using a ball, we can create a three-dimensional model of the Earth and, by performing activities on it, help children move to the globe. Nowadays, using computer animations can further support this learning process. With the help of animation, we can smoothly change perspective,

e.g., move from the surrounding flatness to the sphericity of the Earth. The effectiveness of such activities is described in the article.

1.3. Testing Effectiveness of the Intervention

Educational effectiveness is measured by means of pedagogical experiments in which effectiveness is measured by comparing pretest and posttest results [16,38]. Comparisons to a non-intervention control group are not used. Knowledge testing usually takes the form of an interview [17], sometimes supplemented by an analysis of children's drawings [21]. Tests are used far less frequently to assess children's knowledge [11,39]. Despite its limitations (no possibility to trigger internal models, [40]), a test economically establishes the embeddedness of a concept in the knowledge structure. An example of such a tool is the EARTH2 forced-choice test [40]. It checks whether children use the concept of the Earth's shape to explain other phenomena (e.g., movement of people on Earth).

A posttest conducted in order to assess the effectiveness is usually carried out shortly after the end of the intervention, i.e., two weeks. A certain postponement of the posttest serves to assess knowledge that is well established rather than fresh. In studies conducted with a very short postponement, children have shown to be able to still recall the scientific explanations given during the intervention [15,17]. If the postponement was longer, children gave fewer details and more often tended to return to initial explanations based on everyday experiences [20]. In studies where children's knowledge was tested after several years, it was found that students referred back to everyday experiences [38]. These findings are consistent with the shape of the learning curve and suggest that in the case of concepts that contradict everyday experiences, more frequent repetition is needed. However, there is a concern that the longer the intervention process continues, the more other factors may be affecting the final educational effect, i.e., it becomes more difficult to determine the effectiveness of the intervention as such. Under such conditions, a postponed posttest may lose relevance.

2. Materials and Methods

The aim of the study was to determine the effectiveness of an educational intervention in helping children construct the concept of the Earth's shape through the process of building a cosmological model of the Earth prior to the introduction of a globe. The main method used to achieve the study objective was a pedagogical experiment. It consisted of carrying out an educational intervention among the children and seeing how their views changed, following a series of activities.

The educational intervention was implemented based on an astronomy education programme designed by the author. The programme had been created on the basis of the model of development of basic astronomical concepts [19], precursor model concept [31], and Poddyakov's ideas on constructing a didactic model [37]. According to the developmental model, the concept of the Earth's shape forms the basis for understanding the phenomena seen in the sky (space), the location of people on Earth, the phenomenon of day and night, the phases of the Moon, and the structure of the Solar System.

The main objective of the programme was to support the children in constructing the concept of the Earth's shape and then use this as a starting point for discussing further astronomical topics. The programme was divided into five stages. The first three involved a gradual transition from observing the sky to building a model of a spherical Earth and then replacing it with a globe. The next two stages used the globe to explain more advanced cosmic phenomena. The focus below is on discussing the first three stages as the subject of the research discussed in the article.

The first stage involved a series of activities devoted to sky observation. During these activities, pupils observed the solar eclipse phenomenon. The structure of the sky was discussed with the children, and its movement was simulated with the help of computer programmes (e.g., Celestia, NASA Eyes). Attention was drawn to the regularity of celestial phenomena. The second stage focused on forming a concept of the Earth's shape by creating

a spherical Earth model. For this purpose, a huge inflatable ball with the continents marked on it was placed in front of the children. A small card with a hand-drawn person, clouds, and a car was stuck to its surface. It was explained that *this is where we live and the person is you*. The Google Street app was displayed on a large screen, and the place where we were currently located was found. The view of the immediate surroundings was shown (Figure 1a). It was pointed out that the same place was schematically represented by the drawing attached to the ball (Figure 1b). In the app, the “camera” was lifted to show the street from above and then zoomed out to a view of the city and the continent. An image of a sphere appeared on the screen. The name of a distant location (e.g., New York) was given along with the following suggestion: *Let’s see how people live there*. The animation shifted the view of the planet to show a new area. Then, it zoomed in on the city until the image was magnified to a street view. When asked by the teacher, the children again established how *people walk on the street as we do, drive cars as we do, and there are clouds above them*. The teacher showed the children a second piece of paper with a drawing of a person, clouds, and a car and asked if it was the same on this piece of paper. He stuck it on the ball roughly where New York is, i.e., on the other side of the ball. The lives of people in Australia, Japan, South Africa, Greenland, etc., were analysed in a similar way. During each visit, cards with pictures of people would be attached to the ball. When there were many pictures (Figure 1c), a generalisation was made by pointing out the difference in perspectives in relation to people, cars, and clouds. The following was said: *See, people live on all sides of the planet. Some—relative to us—move upside down*. Similarly, we noted the following: *Cars drive from all sides of the Earth and clouds move over the surface of the whole Earth*.

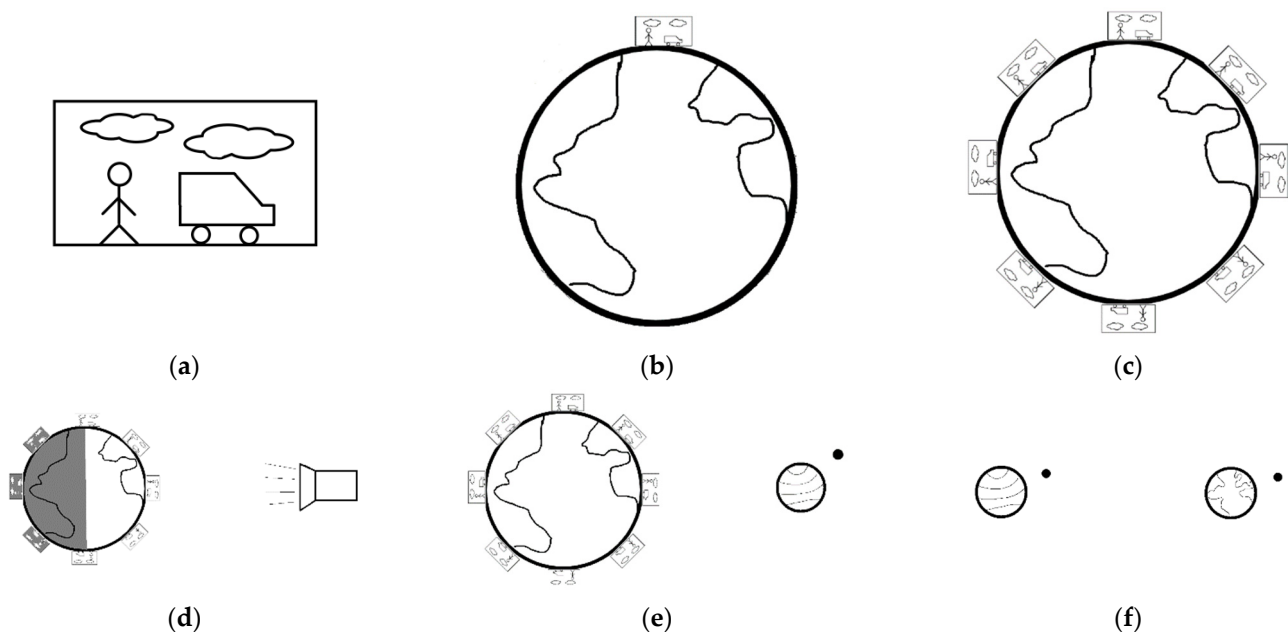


Figure 1. (a) Schematic drawings presented to children; (b) drawing attached onto a large ball to mark current location on Earth; (c) drawings attached to each side of the Earth. Analysis of the location of people, cars, and clouds; (d) simulation using a self-made model of the Earth to illustrate day-and-night phenomena; (e) replacing the self-made model with a ball to illustrate the actual distance between the Earth and the Moon; and (f) replacing the ball with a globe and drawing attention to the lack of visible elements of the Earth.

During the following class, the model of the Earth with cards stuck on was revisited to explain the phenomenon of day and night. The room was dark, and a torch was used to draw attention to the illuminated and unilluminated surface of the ball (planet), as well as pictures of people for whom it was day or night (Figure 1d). Then, the teacher

ran an app demonstrating the position of the planet relative to the sun and showing its current illumination.

In the third stage, the self-made model was replaced by a globe. It was explained that with such a huge ball (Earth), the Moon would have to be several hundred metres away. In order to reduce the distance, the Earth should be reduced to the size of a small ball (Figure 1e). A small ball was then presented to the children, and it was explained that at this distance, the Moon would be the size of a ping-pong ball. The ball was then replaced with a globe of similar size, and it was explained that the globe is already so small that you cannot see all of the people, houses, and even cities on it (Figure 1f). However, *we know they are there*. Using the app, they practised finding out where they lived and marked it on the globe.

The above three stages contain a practical reference to N.N Poddyaakov's concept and the concept of precursor models. A series of activities devoted to the concept of the Earth's sphericity was carried out over seven school classes. The classes took place, implemented once a week (on average) for a period of three months from October to December. The programme was carried out with a group of 47 first- and second-grade primary school students (7 and 8 years old) comprising 24 boys and 23 girls. The selection of students for the study was based on the school's designation by the foundation organising the astronomy education project. The students participating in the project had not previously engaged in astronomy education activities beyond those included in the standard curriculum.

In order to determine the effectiveness of the intervention (experimental factor), a single-group technique was adopted as the experimental method because it allows one to focus on determining the effect of an educational intervention.

The pictorial forced-choice test EARTH2, Earth Representation Test for Children (Appendix A), was chosen as a tool to evaluate the educational effectiveness of the programme. Its answers (pictures) are based on the mental models of Vosniadou and Brewer [3,27]. The assumption was that a child marking a picture would at the same time reveal its mental model. By analysing the marked pictures, it is possible to check to what extent children adhere to the spherical image of the Earth to explain problems such as the location of people, trees, and clouds; the way people move on Earth; and the phenomenon of day and night. The test had been translated into Polish and checked for the possibility that Polish children might reveal other beliefs than those included in the test [19].

The EARTH2 test was used twice during the study. The first was in October, just before the start of the intervention (pretest), and the next was in January, one month after completion of the first three stages of programme implementation (posttest), during which the children were supported in constructing an image of the spherical shape of the Earth. The EARTH2 test is a screening tool that allows one to establish pupils' competencies in a short period of time. This tool has been used to assess the effectiveness of an educational intervention among children in the past [11,39].

3. Results

Previous studies did not usually involve building cosmological models but merely used ready-made ones (e.g., a globe) or referred to objects as substitutes (a ball is the Moon). The study followed Poddiaikov's concept and the concept of precursor models, which involve gradually building a model of a spherical Earth and transferring actual locations to the Earth model in stages (computer programmes were used for this purpose). The effectiveness of such an organisation of the study was demonstrated by the difference between the pretest and posttest.

A pretest to assess students' knowledge prior to the intervention was used to determine whether students already had a well-structuralised idea of the shape of the Earth prior to the activity. The detailed results of the pretest are presented in Appendix B (Table A1). Before the results are presented, it should be noted that a spherical image of the Earth, in addition to scientific answers, was also included in some answers referring to synthetic models (e.g., people only live in the northern hemisphere); therefore, in the presentation

of the results, we make a distinction and separately report about the answers referring to the scientific model and those that simply indicate illustrations (models) that represent a spherical Earth. The study found that, prior to the intervention, one in three students tested (30%, 14 out of 47) consistently adhered to the Earth as a sphere when answering all of the questions without necessarily indicating the scientific answer. In contrast, one in five (19%, 9 students) indicated the correct answers to all questions in the test.

Apart from a few photographs (Figure 2a,b), the activities were not recorded, but after each session, a brief note was written about the children's statements and behaviour.



(a)



(b)

Figure 2. (a) Lesson on the way people live in different parts of the world and attaching pictures to each side of the ball-Earth; (b) the self-made model is replaced by a globe.

Fears around the dangers of asteroids and comets passing close to Earth were evident in the children's questions and behaviour. During the class, each of the dangers was explained using rational evidence, e.g., examples of space projects that have so far been developed to defend against space rocks (e.g., the DART programme).

After completing the series of classes (three stages of the educational programme), the test was repeated. Detailed results of the posttest are included in Table A2 in Appendix B. After the astronomy classes, almost twice as many students as during the pretest (43%, 20 out of 47 students) consistently adhered to the image of the Earth as a sphere and indicated the scientific answers (38%, 18 students). These results confirm the effectiveness of the educational intervention undertaken.

The comparison of pretest and posttest results also took into account the distinction between initial, synthetic, and scientific models (following the classification of Vosniadou and Brewer [3]). All answers (pictures) that represent the Earth as a flat disk were classified as initial models, and those that represented the Earth as a sphere were classified as scientific models. All answers in between were classified as synthetic models (cf. Appendix A).

No change in the children's answers to the test (regarding their correctness) was observed in the case of five children. Further, five children (11%) pointed to the scientific model in all questions in the pretest and posttest. This means that by the time the educational activities started, the pupils already knew the correct answer to the questions in the test. For the remaining 37 children, 142 changes were noted. They were divided according to the direction in which the changes occurred:

- Most changes were progressive (49%, 69 cases). They involved moving from an initial to a synthetic model (9 students). As a consequence, students no longer marked a disk-shaped Earth, whereas moving from a synthetic model to a scientific one (36 students) and from an initial model to a scientific one (24 students) entailed adopting information about the spherical shape of the Earth but also the location of objects or phenomena. All progressive changes consisted of the gradual abandonment of answers derived from everyday observation and the adoption of scientific information;

- Regression was noted in 30 cases (21%). Reverting to previous beliefs was evident in three types of change: (a) regressive changes involving abandoning the scientific model and indicating the synthetic model (21 students), (b) regressive changes involving abandoning synthetic models and indicating initial models (3 students), (b) regressive changes involving abandoning the scientific model selected in the pretest and indicating the initial model in the posttest (6 students). Such changes consisted of a return to a strong impression treating the Earth as a disk as the concept of the Earth's shape is still forming in the conceptual structure;
- No change or a change within the same non-scientific model (from initial to another initial and from synthetic to another synthetic) was present in one in every three cases (30%). This shows that the formation of the Earth's shape concept is still ongoing.

The above results indicate that the procedure used during the intervention was successful. The transition from the flat Earth seen in everyday life to the view of a spherical Earth and building a model of it involved showing two different perspectives. Thanks to the computer animations used, it was possible to show the transition between the two. In turn, the gradual reduction in the self-made model of the Earth, ending with its replacement by a globe, was aimed at supporting the process of abstraction. The children learned that the information that was encoded during the activities on the Earth model (people, clouds, and cars depicted in the pictures) is located on the Earth but is too small to be represented. This form of placing information on the surface of the Earth model (which is close to coding it) was an important part of the transition from flatness to sphericity of the Earth.

During the intervention, no detailed analysis of the children's behaviour was carried out, but a brief note of the activities was written after each meeting. The children's statements and behaviour were recorded in this form. The children brought books about the cosmos and posed difficult questions written down in advance on cards. These questions went far beyond the subject matter of the class and came from media messages. Most often, they concerned space objects flying close to Earth, but there were also questions on preparations for the landing of man on Mars, space missions, and black holes. The particularly challenging questions the children presented were as follows:

- *Is it true that the James Webb telescope has discovered constellations older than the Big Bang, stars formed by the Sagittarius A and B black holes, galaxies that formed some 371,000 years after the Big Bang?*
- *Is there an infinite black hole? One that has infinite mass?*

Asking such questions suggests that first-grade students are curious about topics that are much more distant from what has been planned for them in the curriculum. It was observed that the increased interest in space topics was also related to greater attention to media reports. Many of the questions were about threats from space. During the class, the post-activities undertaken by adults to avoid dangers (such as the DART programme) were explained. All of this indicates that the topics of children's interest go far beyond the curriculum.

4. Conclusions and Discussion

The study has shown that half of all observed changes between the pretest and posttest were progressive, demonstrating the effectiveness of the assumption made regarding the construction of Earth models prior to the introduction of a globe. One in three changes involved the selection of a different synthetic model. In contrast, one in five changes were regressive in nature and involved selecting those images that were closer to everyday experiences. Results of the study confirm the effectiveness of structured educational interventions and demonstrate that appropriately organised educational activities can be effective in supporting children in forming the concept of a spherical Earth [10–12,23]. The findings indicate that constructing a concept is a process related to incorporation into the knowledge structure. All of the changes revealed in the study (progression and regression) are evidence of the child's mind working to align the new concept with its mental structure [31].

Multiple forms of impact were used in the intervention. Coding the figures using pictures on the ball-Earth was an activity that helped the children identify with their place on the ball, whereas sticking more cards on the ball enabled the children to see that both people and vehicles are all around the Earth and do not fall off the Earth. Clouds, on the other hand, form the layer of atmosphere that surrounds the Earth. These issues are important for building further concepts, not only astronomical ones. With a ball as a model of the Earth, a simulation of the day-and-night phenomenon was carried out to better explain this complex phenomenon. The ball model was then replaced by a globe, which was used as a model of the Earth in subsequent activities. Computer animations were also used during the intervention as a form of learning support. Zooming in and out of the image of the Earth on the screen helped to explain what a change in perspective was. Thus, the effectiveness of employing conversations with children [33,34], didactic models, and simulations [11,15], as well as programmes that allow one to switch between the map (visible on the screen) and the globe [2,10,23,35], was confirmed. This list of effective influences can be supplemented by a procedure of constructing a spherical Earth model before introducing a globe as a ready-made model containing a lot of codified data (e.g., inclination of the Earth's axis and distances between cities).

The constructivist approach, which is the pillar of the study described here, is based on the assumption that, during organised activities, children can take the elements they need to build their knowledge of the world. Each of the children, operating at a different stage in the formation of the spherical Earth concept, drew those elements from the activities that were important to them. The fact that not all children have yet grasped the concept and that some of them revealed a regression in the posttest confirms that the integration of the concept of the Earth's shape into the mental structure is a long-term process that requires restructuring (accommodation). The difficulty in mastering this concept confirms previous research findings [18,21].

Research also confirms that changes in the conceptual structure related to the shape of the Earth do not happen suddenly [18]. Rather, they are a gradual process that requires appropriate educational support. When support is lacking, concept development stalls or even regresses, and children resort to the strong image of a flat Earth again [20,38]. Studies conducted among 9- and 10-year-old children who were not taught the shape of the Earth show that half of the respondents gave up the spherical Earth explanation when asked to explain cosmic phenomena [19]. The study also confirms that the development of key concepts (including the shape of the Earth) needs to be addressed quickly to avoid the development of coherent non-scientific models [21].

The intervention triggers children's interest in the topic of space [12]. This, in turn, generates the need to ask questions and sometimes seek answers on their own [11]. Children started to pay more attention to media reports, which, in turn, gave rise to further questions. Their content significantly exceeded the scope of curricular contents intended for the first grade. This, therefore, confirms the need to extend the scope of astronomy education [13]. However, the extension should include issues currently appearing in media messages—space discoveries and space technology. Such an extension of astronomy classes would enliven them and bring them up to date with what is often emphasised in astronomy education [16].

Conversations with the children revealed their fears about space. It seems that for some children, these classes were the first opportunity to think about the existence of dangers from space. During the activities, fears were discussed at length, and actions taken by adults to avoid dangers were explained. This confirms previous research observations [13] and points to the need for a deeper understanding of this area as well as for the development of educational activities that should include alleviating children's fears.

Funding: This research was funded by the NEWAG Foundation, Nowy Sącz, Poland.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institute of Human Development Support and Education, The Maria Grzegorzewska University (date of approval V/2020).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

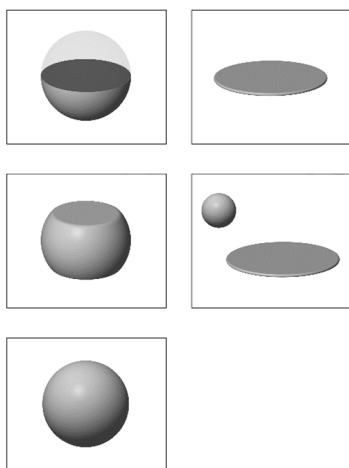
Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: The author declares no conflict of interest.

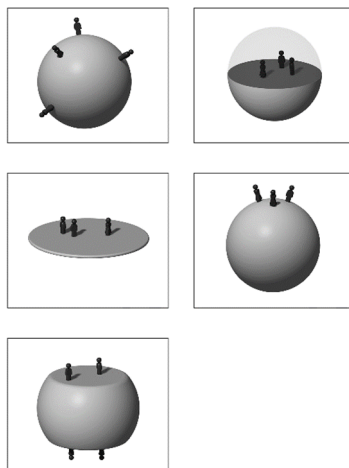
Appendix A

Earth Representation Test for children, version 2 (EARTH2) [40]. In presenting the following questions, the trial question “mark the cat” was omitted; this question was available in the original and online versions.

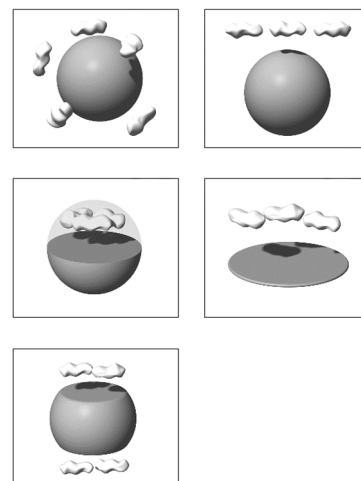
1. What does the earth look like?



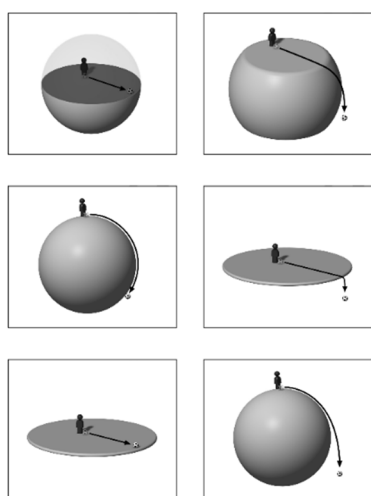
2. Which picture shows best where the people live on the earth?



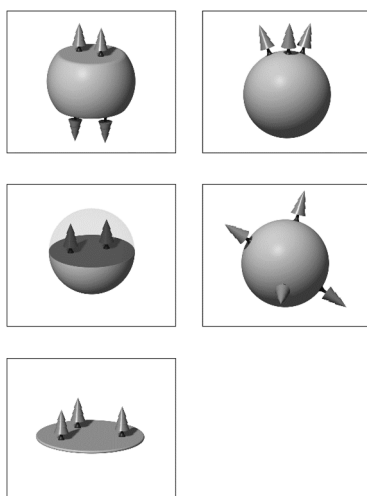
3. Which picture shows best where the clouds are?



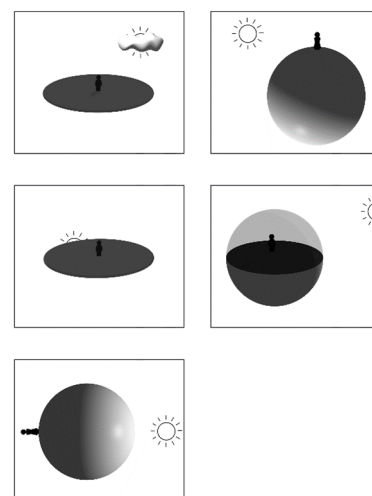
4. Which picture shows best what happens when a giant kicks a ball real hard?



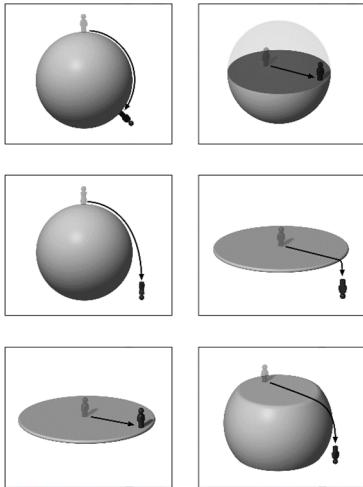
5. Which picture shows best where the trees are on the earth?



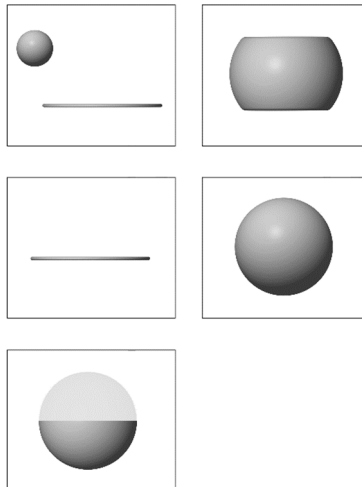
6. Where is the sun at night?



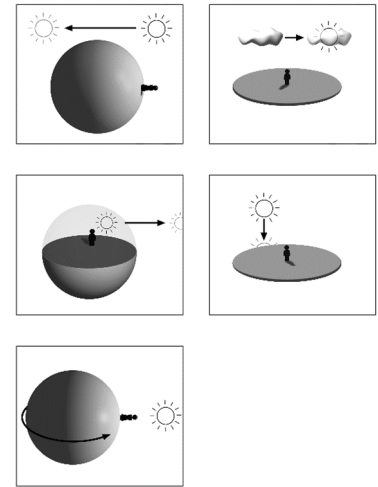
7. What happens when you walk along a straight line for a very long time?



8. Which picture resembles the earth best?



9. Which picture shows best how night falls?



Appendix B

Table A1. Distribution of responses in the test before the educational intervention (pretest).

Question	Initial Model		Synthetic Model				Scientific Model
	Flat Earth	Hollow	Dual	Flattened	No Gravity	Scientific	
1. What does the earth look like?	0	0	1 (2.1%)	3 (6.4%)	-	43 (91.5%)	
2. Which picture shows best where the people live on the earth?	4 (8.5%)	4 (8.5%)	-	0	4 (8.5%)	35 (74.5%)	
3. Which picture shows best where the clouds are?	7 (14.9%)	3 (6.4%)	-	0	5 (10.6%)	32 (68.1%)	
4. Which picture shows best what happens when a giant kicks a ball real hard?	1 (2.1%) Falls off the Earth	6 (12.8%) Does not fall off the Earth	2 (4.3%)	-	1 (2.1%)	13 (27.7%)	24 (51.1%)
5. Which picture shows best where the trees are on the earth?	3 (6.4%)	4 (8.5%)	-	0	7 (14.9%)	33 (70.2%)	
6. Where is the sun at night?	1 (2.1%) Cloud	11 (23.4%) Sundown	1 (2.1%)	-	3 (6.4%)	31 (66.0%)	
7. What happens when you walk along a straight line for a very long time?	2 (4.3%) Does not fall off the Earth	6 (12.8%) Falls off the Earth	1 (2.1%)	-	0	2 (4.3%)	36 (76.6%)
8. Which picture resembles the earth best?	0	0	0	0	-	47 (100%)	
9. Which picture shows best how night falls?	1 (2.1%) Cloud	21 (44.7%) Sundown	0	-	8	17 (36.2%)	

Table A2. Distribution of responses in the posttest of the Earth shape education intervention series (posttest).

Question	Initial Model		Synthetic Model				Scientific Model
	Flat Earth	Hollow	Dual	Flattened	No Gravity	Scientific	
1. What does the earth look like?	1 (2.1%)	0	3 (6.4%)	3 (6.4%)	-	40 (85.1%)	
2. Which picture shows best where the people live on the earth?	3 (6.4%)	2 (4.3%)	-	0	1 (2.1%)	41 (87.2%)	

Table A2. Cont.

Question	Initial Model		Synthetic Model				Scientific Model
	Flat Earth	Hollow	Dual	Flattened	No Gravity	Scientific	
3. Which picture shows best where the clouds are?	4 (8.5%)	2 (4.3%)	-	0	3 (6.4%)	38 (80.9%)	
4. Which picture shows best what happens when a giant kicks a ball real hard?	1 (2.1%) Falls off the Earth	4 (8.5%) Does not fall off the Earth	5 (10.6%)	-	0	37 (78.7%)	
5. Which picture shows best where the trees are on the earth?	4 (8.5%)	1 (2.1%)	-	0	3 (6.4%)	39 (83.0%)	
6. Where is the sun at night?	1 (2.1%) Cloud	5 (10.6%) Sundown	1 (2.1%)	-	2	38 (80.9%)	
7. What happens when you walk along a straight line for a very long time?	0 Falls off the Earth	4 Does not fall off the Earth	3 (6.4%)	-	0	39 (83.0%)	
8. Which picture resembles the earth best?	0	0	1 (2.1%)	0	-	46 (97.9%)	
9. Which picture shows best how night falls?	2 (4.3%) Cloud	9 (19.1%) Sundown	2 (4.3%)	-	-	12 (25.5%)	22 (46.8%)

References

1. Saçkes, M.; Smith, M.M.; Trundle, K.C. US and Turkish Preschoolers' Observational Knowledge of Astronomy. *Int. J. Sci. Educ.* **2016**, *38*, 116–129. [\[CrossRef\]](#)
2. Kampeza, M.; Ravanis, K. Transforming the Representations of Preschool-Age Children Regarding Geophysical Entities and Physical Geography. *Rev. Sci. Math. ICT Educ.* **2009**, *3*, 141–158.
3. Vosniadou, S.; Brewer, W.F. Mental Models of the Earth: A Study of Conceptual Change in Childhood. *Cogn. Psychol.* **1992**, *24*, 535–585. [\[CrossRef\]](#)
4. Mali, G.B.; Howe, A. Development of Earth and Gravity Concepts among Nepali Children. *Sci. Educ.* **1979**, *63*, 685–691. [\[CrossRef\]](#)
5. Gallegos-Cázares, L.; Flores-Camacho, F.; Calderón-Canales, E. Elementary School Children's Explanations of Day and Night. *Sci. Educ.* **2022**, *31*, 35–54. [\[CrossRef\]](#)
6. Frède, V. Comprehension of the Night and Day Cycle among French and Cameroonian Children Aged 7–8 Years. *Cult. Stud. Sci. Educ.* **2019**, *14*, 587–615. [\[CrossRef\]](#)
7. Bar, V.; Brosh, Y.; Sneider, C. Weight, Mass, and Gravity: Threshold Concepts in Learning Science. *Sci. Educ.* **2015**, *24*, 22–34.
8. Agan, L.; Sneider, C. Learning about the Earth's Shape and Gravity: A Guide for Teachers and Curriculum Developers. *Astron. Educ. Rev.* **2003**, *2*, 90–117. [\[CrossRef\]](#)
9. Blown, E.J.; Bryce, T.G.K. The Enduring Effects of Early-Learned Ideas and Local Folklore on Children's Astronomy Knowledge. *Res. Sci. Educ.* **2020**, *50*, 1833–1884. [\[CrossRef\]](#)
10. Baldy, E. Children's Representation of the Earth at the End of Elementary School: The Role of Spherical and Geographical Information Carried by the Globe. *Rev. Sci. Math. ICT Educ.* **2023**, *17*, 5–25. [\[CrossRef\]](#)
11. Özgül, S.G. Integration of Inquiry and Play: Young Children's Conceptual Change in Astronomy. *JIBA* **2021**, *11*, 1–15.
12. Yalçinkaya-Önder, E.; Timur, B.; Özeş, B.; Timur, S. Astronomy Education for Preschool Children: Exploring the Sky. *Int. Electron. J. Elem. Educ.* **2020**, *12*, 383–389. [\[CrossRef\]](#)
13. Raviv, A.; Dadon, M. Teaching Astronomy in Kindergarten: Children's Perceptions and Projects. *Athens J. Educ.* **2020**, *7*, 305–327. [\[CrossRef\]](#)
14. Kampeza, M.; Ravanis, K. Children's Understanding of the Earth's Shape: An Instructional Approach in Early Education. *Skholé* **2012**, *17*, 115–120.
15. Kallery, M. Astronomical Concepts and Events Awareness for Young Children. *Int. J. Sci. Educ.* **2011**, *33*, 341–369. [\[CrossRef\]](#)
16. Lelliott, A.; Rollnick, M. Big Ideas: A Review of Astronomy Education Research 1974–2008. *Int. J. Sci. Educ.* **2010**, *32*, 1771–1799. [\[CrossRef\]](#)
17. Valanides, N.; Gritsi, F.; Kampeza, M.; Ravanis, K. Changer Les Conceptions d'Enfants d'Â Ge Préscolaire Sur Le Phénomène Du Cercle 'Jour-Nuit'. *Int. J. Early Years Educ.* **2000**, *8*, 27–39. [\[CrossRef\]](#)
18. Vosniadou, S. Initial and Scientific Understandings and the Problem of Conceptual Change. In *Converging Perspectives on Conceptual Change: Mapping an Emerging Paradigm in the Learning Sciences*; Amin, T.G., Levini, O., Eds.; Routledge: New York, NY, USA, 2017; pp. 17–25, ISBN 978-1-138-20540-6.
19. Jelinek, J.A. Children's Astronomy. Development of the Shape of the Earth Concept in Polish Children between 5 and 10 Years of Age. *Educ. Sci.* **2021**, *11*, 75. [\[CrossRef\]](#)

20. Hannust, T.; Kikas, E. Changes in Children's Answers to Open Questions about the Earth and Gravity. *Child. Dev. Res.* **2012**, *22*, 89–104. [\[CrossRef\]](#)
21. Hannust, T.; Kikas, E. Children's Knowledge of Astronomy and Its Change in the Course of Learning. *Early Child. Res. Q.* **2007**, *22*, 89–104. [\[CrossRef\]](#)
22. Vosniadou, S. Capturing and Modeling the Process of Conceptual Change. *Learn. Instr.* **1994**, *4*, 45–69. [\[CrossRef\]](#)
23. Shaikh, R.; Padalkar, S.; Stump, G.; Sutar, P.; Kumar, A. Learning Basic Astronomy through an Embodied and Interactive Approach. *Int. Conf. Rev. Res. Sci. Technol. Math. Educ.* **2020**, *3*, 463–474.
24. Wadsworth, B.J. *Piaget's Theory of Cognitive and Affective Development: Foundations of Constructivism*, 5th ed; Longman Publishing: White Plains, NY, USA, 1996; p. xi, 195. ISBN 978-0-8013-0773-7.
25. Ravanis, K. The Physical Sciences in Early Childhood Education: Theoretical Frameworks, Strategies and Activities. *J. Phys. Conf. Ser.* **2021**, *1796*, 12092. [\[CrossRef\]](#)
26. Vosniadou, S.; Skopeliti, I.; Ikospentaki, K. Modes of Knowing and Ways of Reasoning in Elementary Astronomy. *Cogn. Dev.* **2004**, *19*, 203–222. [\[CrossRef\]](#)
27. Vosniadou, S.; Brewer, W.F. Mental Models of the Day/Night Cycle. *Cogn. Sci.* **1994**, *18*, 123–183. [\[CrossRef\]](#)
28. Nussbaum, J.; Novak, J. An Assessment of Children's Concepts of the Earth Utilizing Structured Interviews. *Sci. Educ.* **1976**, *60*, 535–550. [\[CrossRef\]](#)
29. Jelinek, J.A. Children's Astronomy. Shape of the Earth, Location of People on Earth and the Day/Night Cycle According to Polish Children between 5 and 8 Years of Age. *Rev. Sci. Math. ICT Educ.* **2020**, *Forthcoming papers*.
30. Diakidoy, I.-A.; Vosniadou, S.; Hawks, J. Conceptual Change in Astronomy: Models of the Earth and of the Day/Night Cycle in American-Indian Children. *Eur. J. Psychol. Educ.* **1997**, *12*, 159–184. [\[CrossRef\]](#)
31. Delserieys, A.; Jégou, C.; Boilevin, J.-M.; Ravanis, K. Precursor Model and Preschool Science Learning about Shadows Formation. *Res. Sci. Technol. Educ.* **2018**, *36*, 147–164. [\[CrossRef\]](#)
32. Weil-Barais, A. Constructivist Approaches and the Teaching of Science. *Prospects* **2001**, *31*, 187–196. [\[CrossRef\]](#)
33. Lemeignan, G.; Weil-Barais, A. A Developmental Approach to Cognitive Change in Mechanics. *Int. J. Sci. Educ.* **1994**, *16*, 99–120. [\[CrossRef\]](#)
34. Chi, M.T.; VanLehn, K.A. The Content of Physics Self-Explanations. *J. Learn. Sci.* **1991**, *1*, 69–105. [\[CrossRef\]](#)
35. Vosniadou, S.; Ioannides, C.; Dimitrakopoulou, A.; Papademetriou, E. Designing Learning Environments to Promote Conceptual Change in Science. *Learn. Instr.* **2001**, *11*, 381–419. [\[CrossRef\]](#)
36. Prain, V.; Tytler, R. Theorising Learning in Science Through Integrating Multimodal Representations. *Res. Sci. Educ.* **2021**, *52*, 805–817. [\[CrossRef\]](#)
37. Podd'yakov, N. *Preschooler's Thinking*; Pedagogika: Moscow, Russia, 1977.
38. Kikas, E. The Impact of Teaching on Students' Definitions and Explanations of Astronomical Phenomena. *Learn. Instr.* **1998**, *8*, 439–454. [\[CrossRef\]](#)
39. Vaiopoulou, J.; Papageorgiou, G. Primary Students' Conceptions of the Earth: Re-Examining a Fundamental Research Hypothesis on Mental Models. *Ppej* **2018**, *6*, 23–34. [\[CrossRef\]](#)
40. Straatemeier, M.; van der Maas, H.L.J.; Jansen, B.R.J. Children's Knowledge of the Earth: A New Methodological and Statistical Approach. *J. Exp. Child. Psychol.* **2008**, *100*, 276–296. [\[CrossRef\]](#)

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.