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

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Abstract

This article presents findings with regard to mental models of the shape of the earth, location of people on earth and the day/night cycle, established on the basis of statements of 49 polish children aged from 5 to 8 years. During the interviews, the children made moving representations of the day and night sky and explained the position of and mutual relations between the earth, sun and moon using self-made plasticine models. The article establishes a high degree of similarity with the Vosniadou and Brewer models and states that children's astronomical knowledge mainly comes from extracurricular sources of information.

Keywords

Shape of the earth, location of people on earth, the day/night cycle, mental models, children

Résumé

L'article présente les résultats d'une étude sur les modèles mentaux concernant la forme de la Terre, l'emplacement des personnes sur Terre et l'alternance des jours et des nuits. Ces résultats, ils ont été déterminés sur la base des déclarations de 49 enfants polonais âgés de 5 à 8 ans. Au cours de l'étude, les enfants ont construit des images animées du ciel diurne et nocturne. À l'aide de modèle en pâte à modeler, ils ont expliqué les positions respectives du Soleil, de la Terre et de la Lune et les relations mutuelles entre eux. L'article établit une similitude significative entre ces analyses et

les modèles de Vosniadou et de Brewer et indique que la connaissance astronomique des enfants provient principalement de sources d'information non scolaires.

Mots-Clés
Forme de la Terre, emplacement des personnes sur Terre, alternance des jours et des nuits, modèles mentaux, enfants

Theoretical framework

Astronomical phenomena are not easy to observe, and such observations tend to lead to the unscientific conclusions anyway. The appearance of the horizon suggests that the earth is flat, and the perceived (apparent) movement of the sun in the sky leads to the conclusion that the sun and other stars revolve around the earth. Nuances suggesting that this is not the case (e.g. epicycles in the motion of space objects described by Ptolemy) are imperceptible in everyday observations. It took humanity hundreds of years to understand them. The modern astronomical paradigm involves a spherical earth revolving around the sun, rotating around its own axis, orbited by the moon. The origins of the heliocentric model, in which the earth revolves around the sun, go back to the antiquity (Aristarchus of Samos in the 3rd century BC), but was not mathematically proven until the 16th century by Nicolaus Copernicus (1473-1543), only to be declared binding in science thanks to the laws formulated by Johannes Kepler (1571-1630) later. This notwithstanding, the image of the spherical earth outside the centre of the universe is being challenged to this day (e.g. by members of the Universal Zetetic Society).

It took mankind millennia of observations, theory building and often bloody debates (Giordano Bruno, Galileo Galilei) to develop astronomical knowledge. The process of scientific theory development in astronomy only proves how non-intuitive the knowledge acquired in a direct way can be and how many cognitive problems need to be solved in order for this knowledge to be comprehended and adopted. In this context, astronomical education comes down to helping children construct scientific concepts which humanity needed thousands of years of observations and experiments to develop in just a few years.

The theoretical problem

Research into children's reasoning with regard to astronomical objects and phenomena led to the conclusion that, in terms of structure and function, explanations provided by children are similar to scientific theories (Carey, 2007; Gopnik & Wellman, 1992). Children's explanations are based on their own experiences, information acquired from adults or heard in the media (Kampeza & Ravanis, 2009; Mali & Howe, 1979; Özsoy, 2012; Vosniadou & Brewer, 1989).

We do not fully grasp the nature of theories constructed by children, but it seems that when children are born, they have an internal mechanism of processing information (Carey, 2007; diSessa, 1998; Gopnik, 1992; Vosniadou, 2013). This mechanism allows them to create internal, unconscious theories to explain environmental phenomena. The degree of closeness to scientific explanations depends on mental abilities of individual children. According to Gopnik & Wellman (1992), as soon as a theory ceases to describe reality, children abandon it and construct a better one, more suited to new information. Carey (2007) has another opinion and believes that the process in which children develop explanations is rather accidental and resembles spontaneous discovery. DiSessa (1998) in her *Theory Knowledge in Pieces* claims that children do not have permanent theories at all. Instead, they form explanations on the spur of the moment (here and now), combining information every time anew. Vosniadou, on the other hand, believes that certain parts of the emerging theory are fixed (framework), and only some components change (Vosniadou, 2013). As regards theories that explain astronomical phenomena, a representation of the earth's shape could constitute such a framework, from the perspective of which the location of people on earth and the day/night cycle are explained.

Changes in the conceptual structure depend on the acquired information. Sometimes such information is not true (Nobes et al., 2003; Nobes, Martin, & Panagiotaki, 2005). Many adults describe the Solar System in a way that contradicts current theory (Jelinek, 2016). In their explanations, they use mental shortcuts (e.g. saying that the sun has hidden behind the clouds instead of saying that the clouds have covered the sun) or proliferate their ignorance or persistent naive beliefs. For example, to explain the phenomenon of seasons, some adults incorrectly give changes in the distance between the sun and the earth as the reason. This erroneous explanation based on an underestimation of the distance between cosmic objects results from the fact that in books people see a simplified image of the Solar System, in which the distance between celestial objects is presented incorrectly (Jelinek, 2016). Also, media messages are not always tailored to the cognitive skills of children. Children may confuse popular science programs with science fiction films (e.g. Star Wars), which oversimplify the vision of the universe and misrepresent it. With such an image in mind, children then develop misconceptions (Barnett et al., 2006). From messages they receive from adults, children pick and choose whatever fits their explanation of the structure of the universe. In an era of easy access to information about space, they have great difficulties distinguishing between real and false data (Mali & Howe, 1979; Nussbaum & Novak, 1976; Vosniadou & Brewer 1992, 1994). Thus, it is necessary to organise proper astronomy classes (Kampeza & Ravanis, 2012). This is especially important today, as news of new astronomical discoveries are reported by the media almost daily.

Research on children's astronomical representations was first conducted among primary school students (Nussbaum & Novak, 1976; Vosniadou & Brewer, 1992, 1994). But as it became clear that even the youngest respondents were giving the correct

answers, preschool children were included as well. It turned out that already five or six year old children display science-like perceptions (Kampeza & Ravanis, 2009; Nobes et al., 2005; Saçkes, 2015). It was observed that even before children enter school, they have cognitive abilities that allow them to explain in their own words the relationship between the sun, the moon and the earth, in order to explain e.g. the day/night cycle.

Research into mental models in the field of astronomy was conducted among children from different countries of the world: Greece (Vosniadou & Brewer, 1989), USA (Diakidoy, Vosniadou, & Hawks, 1997; Vosniadou & Brewer, 1992), India (Samarapungavan, Vosniadou, & Brewer, 1996), among native American children in North America (Diakidoy et al., 1997), in England (Panagiotaki, Nobes, & Banerjee, 2006), the Netherlands (Straatemeier, van der Maas, & Jansen, 2008) and Turkey (Özsoy, 2012). A lot it if confirmed the descriptions of children's explanations presented by Vosniadou & Brewer (1992, 1994). Regardless of differences in cultures, research methodologies and children's access to scientific knowledge, it turns out that children raised in different cultures undergo a similar transition from explanations based on daily experience to scientific ones (Klein 1982; Nobes et al., 2003; Samarapungavan et al., 1996). Nevertheless, as the experience of Dutch researchers (Straatemeier et al., 2008) shows, one should not directly assume that the mental models of the shape of the earth and the day/night cycle described by Vosniadou & Brewer (1992, 1994) would also apply in other countries. Diagnostic tests in the form of open-ended questions would be needed first (Vosniadou, Skopeliti, & Ikospentaki, 2004). Then, before using tools involving closed-ended questions, generalised explanations of children should be compared to indentify differences and similarities (Nobes et al., 2005).

The research into mental models of the earth's shape, the location of people on earth and the day/night cycle among Polish children was conducted in 2016. The goal was also to determine to what extent the astronomical competence of Polish children is similar or different to mental models of the shape of the earth and the day/night cycle described by Vosniadou & Brewer (1992, 1994). The research was also aimed at determining which cognitive challenges children face learning scientific theories about space. Once cognitive problems of children become known, it will be possible to construct a curriculum that is better suited to children's needs and to organize educational situations in such a way as to help children to solve these problems.

Methodological framework

The overview of the study

The research project carries the name *Children's Astronomy*[1] because of the specific

1 The research project was supported by a grant from The Maria Grzegorzewska University, Warsaw, Poland (nr BSTP 4/16-I).

nature of explanations for cosmic objects and phenomena provided by children. The project was diagnostic in nature and applied inductive reasoning, i.e. generalisations were made on the basis of as much data about the interviewed children and their knowledge as possible.

The aim of the research project was to establish children's reasoning regarding the shape of the earth, the location of people on earth and the day/night cycle. Furthermore, to determine from where they draw their knowledge about astronomical objects and phenomena and to what extent the astronomical knowledge of Polish children is similar or different to that of children brought up in other cultural circles.

The research was carried out using a tool we developed called *Intuicje i zarysy pojęć astronomicznych (Intuitions about and outlines of astronomical concepts)* (IZPA). The research was conducted in the form of individual interviews following the consent of the child's legal guardian and the child itself. The interviews took the form of a relaxed conversation and involved a number of open-ended questions. Three issues were discussed: (1) the day and night sky, (2) the shape of the earth on which people live and (3) the day/night cycle.

While discussing the first issue, children were asked to create a moving representation of the day and night sky. From a set of coloured sheets of paper, they chose one for the background. Then they placed a ready-made shape of the horizon (trees and outlines of buildings in black) at the bottom edge of the sheet and added celestial objects they drew on pieces of coloured paper. Using the movable elements, the children talked about the position and movement of celestial objects in the day and night sky. During the conversation about the shape of the earth, they used modelling clay (plasticine) to make the earth, the moon and the sun. Then they attached Lego minifigures to the plasticine earth to show there on the planet they lived. After the location of people on earth was established, they manipulated the plasticine sun and moon representations to illustrate day and night on earth.

A total of 49 children were interviewed using the IZPA tool, including 19 five-year-olds, 8 six-year-olds, 10 seven-year-olds and 12 eight-year-olds (average age was 6 years). The group consisted of 27 girls and 22 boys. 25 children lived in a small town (40,000 inhabitants) and 24 in the countryside. Both children from urban and rural areas were included in order to collect a possibly diverse range of mental models. The existence of differences was probable as night-time illumination in cities is much higher than in the countryside, and thus the visibility of stars is lower in cities than in the countryside. The same problem also applies to the limited visibility of the horizon line in cities, as it is obstructed by architecture. The division into town and country children was aimed at collecting as many different explanations as possible rather than making comparisons between the explanations of town and country children.

After interviews with the young respondents were completed, we analysed the children's behaviour and statements, and created an individual report card for each child. The reports described how each of them understood and imagined the shape of the earth, the location of people on earth and the day/night cycle. On the basis of these explanations, we made a generalisation by dividing similar explanations of children into groups. In this manner we created mental models, which were then compared with the mental models described by Vosniadou and Brewer (1992, 1994).

RESULTS

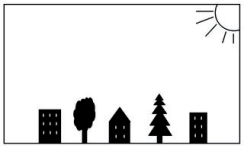
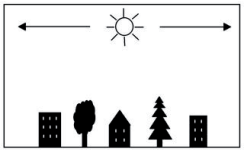
Presenting the findings, we shall disregard the analysis of colour selection and the graphical analysis, and only focus on the location and mutual relations of cosmic objects as presented by children during the interviews.

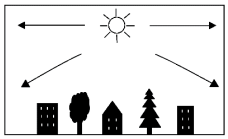
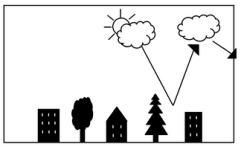
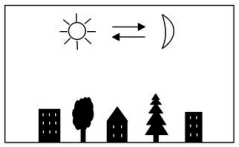
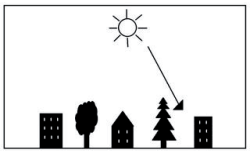
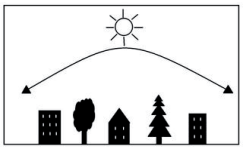
Day sky

When preparing the representation of the day sky, all the children included the sun. The children were asked about the position of the sun in the morning, at noon, in the evening and at night. On the basis of the children's answers, 7 similar descriptions were created. The descriptions with pictures and comments are listed below. The graphic representation of mental models corresponds with the children's descriptions and their gestures as they pointed to the positions and movements of the sun.

TABLE 1

Mental models of the position and movement of the sun in the day sky

	1. *The sun is located in the corner of the drawing as a quarter circle.* This model was presented by one school student. In the explanation the child said that *The sun is in the corner* and could not describe its movement in the sky.
	2. *The sun is only in the upper part of the drawing, i.e. in the upper part of the sky.* It only moves along the top edge of the page. This was the most common description among the interviewed children (18). Maciek explained it in the following way: *The sun is above, it cannot be behind the trees, because then it would be on the ground, and it must be high and nothing can cover it.* Kuba in turn gave the following explanation: *The sun can't be low because it would burn the trees.* In his opinion, in the morning the sun is on the left (or right) side of the page, at noon it is in the middle of the upper edge and in the evening it is on the right (or left) side of the upper edge of the page.

	*The sun can be anywhere, at any place in the sky*. Four children (three preschoolers and one school student) made a moving representation that involved such a vision of the sun's motions. These children were convinced that the sun could be literally anywhere, even at the bottom of the page - near the horizon. When I asked them for an explanation, they pointed to different places on the page or mentioned the place where the sun rises and sets.
	*The sun moves in the sky, in the evening it descends, and at night it rises and hides in the clouds*. This description of the sun's behaviour was presented by ten school students. Maja, when asked where the sun was, first covered the sun image with a cloud, then took the sun image off the picture and hid it under the blue background page representing the sky (pictures 1 and 2). In this way she made it clear that this was how she understood the situation when the sun is not visible in the sky. Many children said that at night there was no sun. When asked by the interviewer where the sun was, they answered: *Nowhere* or added: *It is shining in another country*.
	*The sun and the moon alternate in the sky*. The following dialogue in response to the interviewer's question about the location of the sun in the morning can serve as an example of such an understanding of the apparent movement of the sun: *Where is the sun in the morning?* – Piotr pointed to the upper left corner and said: *Here*. When asked: *And where is the sun at noon* – he pointed to the opposite corner (upper right) and said: *Here*. When the interviewer asked: *Where is the sun in the evening?* – the boy explained: *behind the trees. And at night? – The sun hides behind the moon.* According to some children, the sun is visible in the sky during the day but when the night falls the moon appears and the sun hides behind it.
	*The sun moves in the sky on a diagonal line from the sky to the earth*. Such a vision of the sun's movement was presented by two school students. They showed the direction with gestures, which I then marked on the drawing with a diagonal line/ They explained that in the evening the sun moved like that and *…disappeared*. When asked: *Where is the sun in the morning?* – they explained that the sun was in the sky and pointed to the top of the page.
	*The sun moves in the sky in an arc*. Six students presented the sun's movement in this manner. They pointed with their fingers to the beginning of the arc as the location of the sun in the morning, the middle as the location of the sun at noon and the other end as the location of the sun in the evening. Then they took the sun off the moving picture and explained that at night there was no sun. One of the children – Karolina –added that: *The sun is now (at night) on the other side of the planet.*

To conclude the presentation of the movement of the sun on the picture of the daytime sky, we will quote the explanation of Maja, who, explaining the position of the sun at night, hid the sun drawing behind the clouds (Her explanation is typical of the following model: *The sun travels in the sky, in the evening it descends, and at night it rises and hides behind a cloud*). Figure 1 shows the moment when the girl covers the sun picture with a cloud picture.

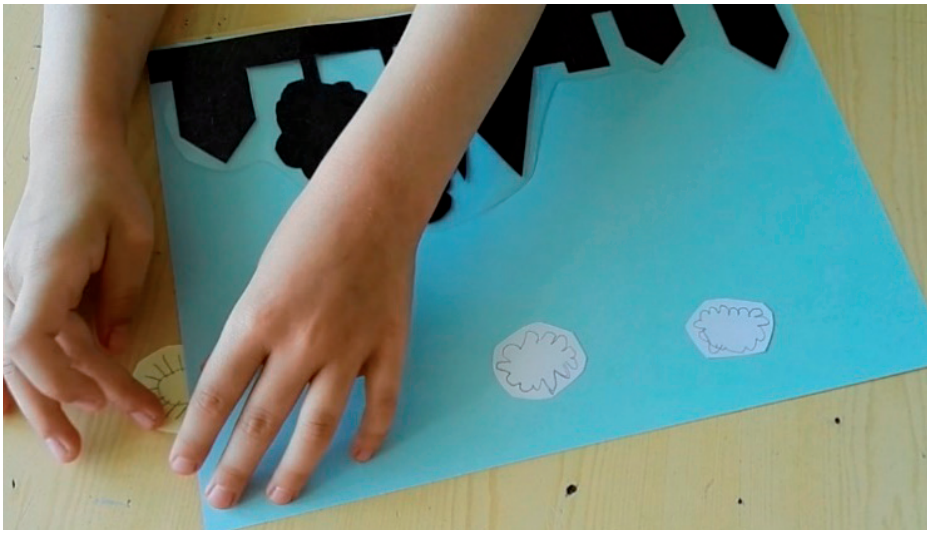
Figure 1

Girl hides the sun image behind a cloud image to indicate the position of the sun at night

Figure 2 depicts the moment when Maja hides the sun under the sheet of paper that represents the day sky (Figure 2). We will add that the girl's action (hiding the sun under the moving representation of the day sky) was accompanied by an explanation that at night the sun cannot be seen.

Making the day sky, many children used cloud pictures to explain the position of the sun (e.g. hiding behind clouds). Based on children's statements and behaviours, we was able to arrange the positions and movements of clouds in the sky into three models: (1) *Clouds are high in the sky and never move;* (2) *Clouds are at the upper edge of the sheet representing the sky, during the day they only travel along the top of the sheet;* (3) *Clouds can be anywhere in the day sky, and the rising fog creates clouds*. Two school students expressed views on the clouds that were similar to scientific ones: Kasia explained that *Clouds can be low because there is fog*, and Michał said that *Clouds are pushed by the wind*.

FIGURE 2



Girl hides the sun image behind to background sheet (sky) indicating the position of the sun at night

Night sky

Making a moving representation of the night sky, all the children mentioned the moon as an object that can be seen in the night sky. After analysing the moving representations of the night sky and the children's statements, we was able to identify three locations and movement patterns of the moon in the night sky preferred by the children:

1. *The moon is depicted as a stationary object.* The children claimed that the moon does not move, it stays in one spot, which they located it in the left or right corner of the moving night sky representation.
2. *The moon moves along the upper edge of the sheet which represents the end of the sky*. Most children placed the moon close to the upper edge of the picture. With a gesture they showed the moon's movement from left to right and back. When asked by the interviewer: *Can the moon also be lower?,* Monika replied: *Not behind the trees... Not between the houses... It can only be at the top.* Zenek placed the moon drawing low in the night sky and explained: *It can be low between the trees, but it can't be behind the houses, because you can't see a piece of the moon and it can't be hidden behind the house.*
3. *The moon may be high in the sky or low above the ground.* This location of the moon in the night sky was indicated by five of the interviewed children. However, they were not able to explain how the moon moves in the night sky.

The same as the mental models of the position and motions of the moon in the night sky, it was also possible to identify three models of the position and motions of stars in the night sky: (1) *The stars do not move and can only be at the top of the sheet*, (2) *The stars stay high but move*, (3) *The stars move and can be in different places in the sky*. Most children (25) pointed to the first model, i.e. claimed that the stars were immobile.

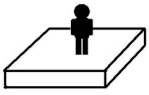
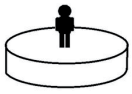
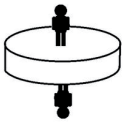
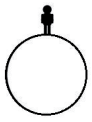
Shape of the earth and place of people on it

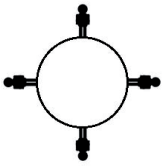
When asked to present the shape of the earth as a plasticine image, the children would make one of three shapes: (1) a spherical shape of the earth (35 children), (2) a flat disc (12 children) and (3) a strongly flattened cuboid (2 children).

When the shape was ready, the interviewer gave children six Lego minifigures with the instruction to place them on the plasticine earth where people live. Based on the plasticine shapes, locations of the figurines and children's descriptions, it was possible to distinguish five mental models that determined the location of people on earth.

TABLE 2

Mental models of the location of people on earth

	1. *People live on the surface of the earth, which is a flat cuboid*. This is how two preschool children presented the shape of the earth and placed people on it.
	2. *People live on the upper surface of the earth depicted as a flat disk*. Such a representation the earth's shape and the location of people on it was presented by 11 children. When asked by the interviewer whether people could live on the other side of the disk, they vigorously denied, explaining that they would fall off.
	3. *People live on the upper and lower surface of the earth depicted as a flat disk*. This model was proposed by one preschooler. When asked if people living on the bottom of the disk wouldn't fall, the child replied: *You can't fall off the earth*.
	4. *People only live at the top of the spherical earth*. The earth as a spherical (ball-shaped) planet was presented by nine children. They all located people in its upper part. When the interviewer pointed to the bottom part of the sphere and asked if people could live there, their answer was a definite: *No*.

	5. *People live on all sides of the spherical earth*. This understanding of the shape of the earth and the location of people on it is close to the scientific model. It was presented by the highest number (26) of the interviewed children. These children, too, were sure it was not possible to fall off the earth. Schoolchildren pointed out that: *People don't fall off because the earth pulls them to itself*. Four children used the word *gravity* but could not explain what it was.

The Solar System and the day/night cycle

After the children made the earth shape from plasticine and put people on it, they were given two additional lumps of plasticine - a red and a grey-black one. They were asked to fashion the sun and the moon out of them. Depicting the shape of the sun, the children formed a flat round disc or a ball. Some children added plasticine *dashes* to the main shape, explaining that these were sun beams. Oliwia (a preschooler) took modelling clay in her hand and even said that she could not make it into the sun, because there were no "sticks" to make sun beams. These children were convinced that the beams were a vital feature of the sun's shape. A lot of them however gave the plasticine the shape of a ball (without rays), saying this was the sun. As regards the moon, most preschool children depicted it as a flattened croissant.

After forming the earth, the sun and the moon from modelling clay, the children were asked by the interviewer to explain the cycle of day and night by using the astronomical objects they made. Children's words were written down, and their manipulations with plasticine models of the earth, the sun and the moon were photographed. After analysing the results, we identified 16 different explanations for the day and night phenomenon. Every variant was represented by at least two children. We will relate them starting from those that most reflect personal experiences to nearly scientific ones:

TABLE 3

Mental models of the day/night cycle (S – sun, M – moon, E – earth)

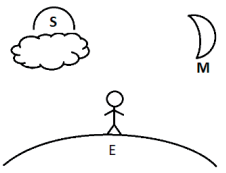
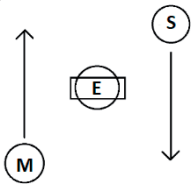
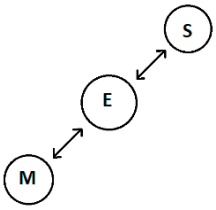
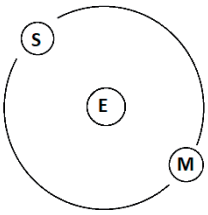
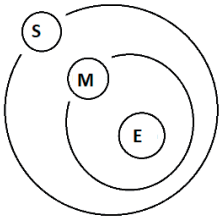
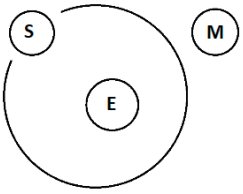
	1. *Day and night happen when a cloud covers the sun and the moon*. Explaining the night phenomenon, the children flattened the modelling clay to form a flat disc and said that a huge dark cloud covered the sun and revealed the moon. This description resembles the phenomena that can be observed in the day sky.

TABLE 3

	2. *Day and night are caused by the sun and the moon orbiting each other.* The children explained that when the sun is closer to the (flat) earth, it is day time, and when the moon is closer to the earth, it is night time. That's because the moon and the sun revolve around each other.
	3. *Day and night are the result of the alternate appearance of the sun and the moon in the sky*. From the children's explanations it was clear that the earth is flat (or spherical) and does not move. The sun and the moon float over it: *In day time, you see the sun, the moon is not there. At night you see the moon, and the sun is not there.*
	4. *The day/night cycle is the result of the alternate movement of the sun and the moon towards the earth*. Some children thought that the earth was stationary and the moon and sun were moving. Some believed that the alternate movement towards and away from the earth took place on opposite sides of the immovable planet. Others were convinced that the sun and the moon were above the earth. The day/night cycle was explained by the sun moving closer to the earth (*then there is day on earth*) or the moon (*then there is night on earth*). Children presenting this explanation believed that the time of day is the same all over the planet.
	5. *Day and night are caused by the revolutions of the sun and the moon around the still earth*. According to some children, the sun and the moon circulate around the earth in the same orbit. If the sun is on one side of the earth, it is day there and night on the other side of the planet (and vice versa).
	6. *The day/night cycle is the result of the sun's approaching and moving away from the earth*. According to some children, the earth is stationary and the moon and the sun revolve around it on different orbits. If the sun is closer to earth, it is day. If the moon is closer to earth, it is night.
	7. *Day is caused by the sun that illuminates the surface of the earth*. The sun revolves around the stationary earth. According to the children, the earth and the moon are immobile and far away from each other. Day comes on the part of the earth that is lit by the sun revolving around it. And on the rest of the earth it is then night.

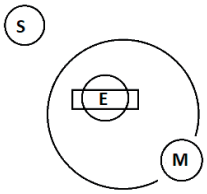
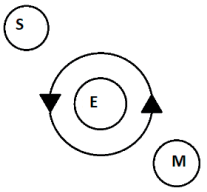
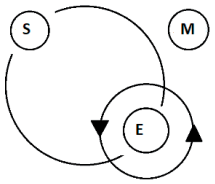
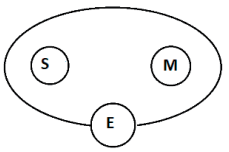
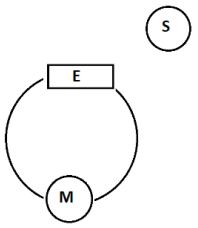
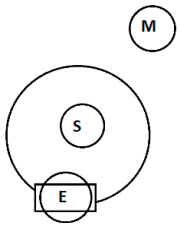
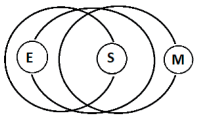
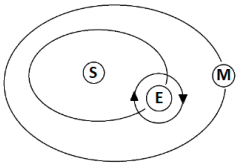
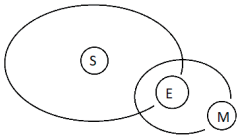
	8. *Day and night are caused by the moon moving away from the earth.* The sun and the earth are stationary and the moon travels around the earth. Day comes on the part of the earth's surface from which the moon moves away.
	9. *Day and night are caused by the rotation of the earth around its own axis*. For some children, the sun and the moon are immobile, and day comes on the part of the earth that faces the sun. At the same time, on the other side of the planet (facing the moon) it is night.
	10. *Day and night happen when the earth moves away from the moon.* The children thought that the moon is fixed and the earth spins around its own axis. Additionally, the earth and the sun travel in the same orbit. These children believed that the day/night cycle is the result of the earth moving away from the moon.
	11. *Day and night are caused by the revolutions of the earth around the stationary sun and moon.* An example of such a take on the day/night cycle can be found in the following explanation: *The earth revolves around the sun and the moon. The earth is still*. If the earth approaches the sun and moves away from the moon, then it is day time on earth, if the earth moves closer to the moon (moving away from the sun), it is night time.
	12. *Day and night are the effect of the earth moving closer towards and further away from the sun.* These children believed that the sun is stationary and that the (flat) earth and the moon move in the same orbit (but not around the sun). Day occurs as a result of the earth moving closer to the sun.
	13. *Day and night occur as the earth moves away from the immovable moon*. Here are three examples of such explanations: Gabriel and Paweł were convinced that the (flat or spherical) earth travels around the sun, and the moon is immobile. When the earth moves away from the sun, night starts. According to Gabrysia, the earth revolves in the same orbit as the moon, moving closer to the sun (day) or further away from it (night).

TABLE 3

	14. *Day and night are caused by the earth approaching the sun.* In this explanation, children explain that all objects are in motion and revolve. The earth and the moon orbit the sun, and the sun additionally orbits the earth. Day occurs as the earth moves closer to the sun, and night as the earth moves away from it.
	15. *Day and night occur as a result of the rotation and revolution of the earth around the sun as well as its distance from the moon.* Two (preschool) children stated that the earth spins around its own axis and orbits the sun. The moon revolves around the sun in a separate orbit. Day occurs as the earth moves closer to the sun, and night as it moves away from it.
	16. *Day and night are caused by the rotation of the earth around its own axis. The earth additionally moves around the sun and the moon orbits the earth.* Only two of the interviewed children (one preschooler, one school student) presented this vision of the Solar System (close to the scientific one). The day/night cycle was explained by earth's revolution around the sun. This is how Zosia (preschooler) put it: *If you want to have day here* (gesture), *this side of the earth must face the sun*.

The descriptions of all 16 explanations (for 49 interviewed children) seem to exhaust all possible combinations of the earth-sun-moon relationship. Initial models, synthetic models (divided into geocentric and heliocentric models) as well as scientific models can clearly be identified among them.

Analysing the explanations provided by the children, we discovered that they applied two mental rules to build their explanations: consequence and contradiction. The first one – *the rule of consequence* – was used to explain that the sun was responsible for the emergence of day and the moon for the emergence of night. The consequence rule was evident in those explanations where the children explained that night was where the moon was and day was where the sun was. When they constructed the plasticine earth, they would explain that day was where the sun shone above the surface of the disc, or - if the plasticine shape was spherical - then the time of day affected the whole planet (or a part of it) in the same way.

The rule of contradiction is apparent in the way children explained that the moon and sun cannot be side by side. Depicting the earth-sun-moon relationship, children would manipulate plasticine objects to put the moon in opposition to the sun. The rule of

contradiction was also apparent where children explained the alternate appearance of both celestial objects. When asked to explain the emergence of day on earth, they would raise a lump of plasticine (the sun) above the earth and at the same time move the plasticine moon away from the earth.

Departure from the rules of consequence and contradiction seems to be the prerequisite of developing a scientific understanding of the day/night cycle. An analysis of the explanations provided by the interviewed children shows that none of them has managed to achieve it yet. Out of 49 examined children, Zosia (a preschooler) and Kacper (a first grader) were closest to a scientific explanation of the day/night cycle.

Sources of children's knowledge about astronomical objects and phenomena

During conversations about the shape of the earth, the location of people on earth and the day/night cycle, the children were asked questions such as: *How do you know that? Where did you learn that?* According to the children's statements, the information about the day and night sky is most often obtained by direct observation. Children most often obtained information about the shape of the earth by watching television and pictures in books about nature. On the other hand, when explaining how they know about the location of people on earth, the children who described a vision far from the scientific truth (e.g. people live on a flat earth) referred to everyday observations (because this is what they saw). Children who explained that people lived on the entire planet had difficulty naming the source of their knowledge, but their statements suggested that their parents explained it to them. The source of information about the causes of the day/night cycle turned out to be television, books and adults. Situations in which children mentioned teachers were an exception.

The findings show that school education only in isolated cases serves as the source of astronomical knowledge. Children rarely learn from illustrations in books - probably because they are static and do not show the movement of objects e.g. in the Solar System. Many children benefit from knowledge passed on by adults (parents, grandparents) and from television programmes watched together with adults as part of home education. However, the most frequently mentioned source of information was their own experience.

Comparison of mental models of Polish children with mental models of children raised in other cultural circles

Comparing the creations and explanations of Polish children with the generalised mental models described by Vosniadou and Brewer (1992, 1994) we found a strong similarity. Minor differences that were identified when comparing the descriptions were due to the different methods used. Conducting research among Polish children, we allowed them to act and express their thoughts at the same time, to create moving

representations to depict changes in the day and night sky and to identify and discuss astronomical objects and phenomena presented in the photographs. Whereas research on the astronomical knowledge of children from other cultures involved verbal methods supplemented by children's drawings by Vosniadou and Brewer (1992).

Despite these similarities, there are some differences in children's deliberations about the shape of the earth and the location of people on it. Statements of the Polish children did not include certain reflections revealed by researchers studying the astronomical knowledge of children raised in America and India. In these cultural circles, children's mental models classified as synthetic involved the *dual earth model* and the *hollow sphere model*. None of the 49 Polish interviewees described the shape of the earth in such a way or located people on it in a similar manner.

Comparing the 16 mental models of the day/night cycle, we found some similarities and some differences. Similarities apply to all three types of mental models (initial, synthetic and scientific) described by Vosniadou and Brewer (1994). We found that each of the Polish models can be assigned to one of the models described by Vosniadou and Brewer. Differences in the descriptions are due to the level of generalisation, which in the research procedure of Vosniadou and Brewer was performed several times.

Discussion

Individual differences between the interviewed children revealed a rich knowledge of astronomy, and the children's statements could be arranged into initial, synthetic and scientific models. The comparison of mental models of Polish children led to the conclusion that they are not significantly different from mental models found among children from other cultural circles.

Now that a high level of similarity has been established, current scientific findings in the area of astronomy may with greater certainty be treated as valid in Poland as well. It also opens up the possibility of using research tools developed on the basis of these findings, such as the EARTH2, *Earth Representation Test for Children* (Straatemeier et al., 2008). This test was used in subsequent studies (Jelinek, 2019) to determine dominant mental models among children between 5 and 10 years of age. It was also used to determine the effectiveness of peer tutoring among preschool and school children in discussing such issues as the shape of the earth, the location of people on earth and the day/night cycle (Jelinek, 2019).

In addition, the research has shown that as regards initial, synthetic and scientific mental models children's astronomical knowledge is not homogeneous in terms of the level and precision of reasoning. Children explaining the shape of earth, the location of people on earth, and the day/night cycle do not always give answers that consistently represent one level only (e.g. synthetic). Some children's statements that have been

categorised as initial models included opinions containing information obtained from adults or heard in the media (synthetic). Other statements that have been categorised as synthetic included explanations that were similar to initial models based on everyday experience and some that were similar to scientific explanations. This heterogeneity of children's explanations proves that each of the discussed representations - the shape of the earth, the location of people on earth and the day/night cycle - is formed in children's minds at different times. The actual time is determined by the amount of experience children gather. In one area where the child has gained more knowledge, his or her explanations are closer to scientific ones, while in another area the knowledge can still be very poor and the child may still display initial models.

Children who, when asked about the shape of the earth, formed a sphere out of modelling clay, and when asked about the location of people, changed its shape into a flatter one, seem to have difficulties in transferring the horizontal perspective (everyday experience) onto a spherical planet. This is confirmed by the findings of Kampeza & Ravanis (2009), who analysed children's perceptions of geophysical phenomena from different perspectives, including the horizontal perspective and the perspective of space.

The analysis of the sources of children's astronomical knowledge led to the conclusion that the impact of school education is negligible. Apart from their own experience, the development of astronomical knowledge in children is greatly influenced by information provided by adults and the media. This confirms earlier findings of Özsoy (2012), who points out that such sources of information may give rise to misconceptions. Similar findings are reported by Samarapungavan et al. (1996), who point out that when children have access to scientific and non-scientific theories (i.e. culturally accepted popular explanations), they take from each whatever they need to build their own explanation.

Astronomical knowledge of children is determined by their mental abilities and a characteristic confrontation of personal experience with information provided by adults or television broadcasts, the Internet, etc. Due to the fact that children's knowledge of astronomy mainly develops outside the framework of school education, next to their intuitions, they use outlines and concepts similar to scientific ones. This creates the impression that children's astronomical knowledge develops chaotically, and so it takes a long time until they adopt the scientific explanation of astronomical objects and phenomena. At the same time, it is astonishing that they can arrive at such complicated, abstract conclusions as the astronomical ones actually without any education involved.

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