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THE INFLUENCE OF EXPERIMENTAL TEACHING ON 5 - AND 7-YEAR OLD CHILDREN'S CONCEPTS OF THE EARTH AND GRAVITY

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Abstract. The investigation was aimed to study the influence of age and experimental teaching conditions on the learning of the concepts of the earth and gravity. 47 kindergarteners (age 60-69 months) and 56 first graders (age 85-95 months) were assigned into three groups: model-based, verbal-individual teaching and control groups. Three topics, aimed to treat children's preliminary notions and to change children's entrenched beliefs, were covered in teaching: the spherical shape of the earth; gravity; the relativity of up-down direction. The results showed that both 5- and 7-years-old children's astronomy knowledge was improved due to teaching, regarding of which teaching method was used; however, the condition x age interaction was not significant. Difficulties that occurred during learning and their sources are discussed and conclusions for education are drawn.
Key words: gravity, earth, experimental teaching.

Introduction. The trends in education show that children are first taught about the earth and gravity at younger and younger age (e.g. Sharp, 1996). While Piaget (1929) stressed that the scientific astronomical concepts are too abstract and, therefore, beyond primary school pupils' understanding, the topic is taught in first grades now (Sharp, 1996; Vosniadou, 1996). However, studies have shown that even older children experience difficulties in understanding this knowledge. Two different but interrelated sources of these difficulties have been identified: 1) everyday concepts differ form – even contradict – scientific concepts taught at school and 2) the teaching-methods used in ordinary schools are inappropriate (e.g. Diakidoy & Kendeou, 2001; Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001).

Everyday versus scientific concepts. Everyday concepts develop from concrete perceptible instances (e.g. the visible flat surface of the earth). The initial model that children develop is of flat earth which is supported by something (e.g. ground or water). At school, new – scientific – explanations are taught; it is done mainly by verbal explanations, although models (pictures, diagrams etc.) are also used. As this knowledge is mediated by signs, it becomes possible to talk about out- of-daily-life experiences (e.g. about the shape of the earth as spherical) (see Vygotsky, 1994; Wertsch, 1998). However, new psychological resources are necessary to learn scientific concepts as compared with the acquiring of the everyday concepts. The terms used are abstract and sometimes their everyday meaning is different from the scientific one (e.g. round for three-dimensional sphere as opposed to two-dimensional circle). Therefore, the abilities to abstract, compare and differentiate between concepts are necessary (Vygotsky, 1994). These resources may be not yet developed in young children.

Understanding scientific explanations is especially complicated if the new knowledge contradicts the previous everyday knowledge. It is just what happens during learning about the earth and gravity. During learning, children are confronted with several inconsistencies that need resolution: what children see in everyday life (e.g. the flat surface of the earth) contradicts what they study (i.e. the earth is spherical). Children either tend to memorise fragments (Vosniadou, 1994) or form new synthetic models (Baxter, 1995; Diakidoy, Vosniadou, & Hawks, 1997; Vosniadou & Brewer, 1992).

Teaching astronomy at school. It has been widely documented that traditional astronomy teaching does not take into account students' preliminary knowledge; a lot of new information is given, but there is not enough time for discussions and comparing the new and previous knowledge (e.g. Diakidoy & Kendeou, 2001; Kikas, 1998; Vosniadou et al., 2001). The way in which new knowledge is acquired is also constrained by the existing domain-specific knowledge: students interpret the new information in the context of their earlier knowledge.

Researchers and educators have also looked for new and better ways of teaching. It has been shown that to make the learning more efficient, it is necessary to 1) explicitly talk about preliminary everyday knowledge to make it conscious; 2) show the inconsistencies between everyday and scientific explanations and their reasons; 3) verbally teach the new explanations and give time to think and discuss about them; 4) use models and analogies to enhance the understanding (Chi, 1992; Diakidoy & Kendeou, 2001; Smith, Maclin, Grosslight, & Davis, 1997; Vosniadou et al., 2001). However, it should be stressed that models (also diagrams and schemes) which are used to facilitate understanding, are not the direct diminished copies of the reality but mediate the phenomena and communicate the implicit information as well (Grosslight, Unger, Jay, & Smith 1991). If this implicit information is not understood, misunderstandings may arise (Kikas, 1998; Michaels & Bruce, 1989). So, learning with the help of models is not similar to learning in everyday life. Usually even models need to be explained verbally (see also Vygotsky, 1994).

According to the Estonian National Curriculum ("Põhikooli ja gümnaasiumi", 2002) the earth's shape and position in the Solar System, day/night cycle and seasonal changes are taught already in the first grade (pupils' age about seven years). On the one hand, such early starting is justified because young children like to explore the nature and look actively for explanations (Brewer, Chinn, & Samarapungavan, 2000); on the other hand, children may lack important psychological resources necessary for understanding the new out-of-experience information (Vygotsky, 1994). Learning scientific concepts puts great demands on children's abilities; but, also, it takes time and effort. Pupils have to make sense of the verbal information which may be quite abstract.

The investigation was aimed to study 5- and 7-year old children's everyday astronomy concepts and the possibility and efficiency of teaching scientific concepts of the earth and gravity to these young children. The teaching was designed on the basis of previous works (Smith et al., 1997; Vosniadou, 1996; Vosniadou et al., 2001). The emphasis was paid on treating children's initial beliefs and contrasting visible and verbal knowledge. The efficiency of two different experimental teaching methods was compared. Models, analogies and group work were used in some classes while verbal individual teaching was carried out in others.

Method

Participants

54 kindergarteners (age 60-69 months) and 62 first graders (age 85-95 months) participated in Pre-test. 13 children fell ill and could not participate in the teaching sessions. We analyse the answers of 103 children (47 kindergarteners and 56 first graders) who also participated in the Post-test.

Children were randomly assigned into three groups. 37 children (18 kindergarteners and 19 first graders) formed experimental groups with model-based teaching, 35 children (17 kindergarteners and 18 first graders) with verbal individual teaching and 31 children (12 kindergarteners and 19 first graders) acted as controls.

We included into the study only those children who stated verbally that the earth is round (or spherical) but whose conceptual knowledge was not perfect. We expected these children to be ready for learning, as they were inconsistent in their answers (cf. Siegler & Chen, 1998).

Procedure

1. Pre-test. Children's knowledge of astronomy was assessed before teaching. Children were interviewed individually.

2. Teaching experiment. In model-based condition, children were taught 7 times in small groups (2-4 children). In the eighth session, all the topics were repeated once again. Models and analogies were used at lessons, children were also encouraged to discuss problems. In another condition, children were taught individually. During teaching, neither models nor pictures of the spherical earth were shown. The majority of the time, the teacher explained the material verbally, although in some sessions some materials (e.g. magnet and nails) were used (see Appendix). Lessons were given twice per week and lasted for around ten-fifteen minutes each.

Three topics, aimed to treat explicitly children's preliminary notions and to change children's entrenched beliefs, were covered in the lessons (cf. Vosniadou 1996): 1) the spherical shape of the earth; 2) gravity or falling of objects toward the centre of the earth; 3) up-down direction, connected with the direction toward the centre of the earth. Aims, materials and tasks of the lessons are described in the Appendix.

All the sessions were audiotaped, transcribed and analysed. In the beginning of each lesson, children were questioned about the topics that had been covered in the previous session.

3. Post-test. The same tasks and mode of presentation as in Pre-test were used to determine children's knowledge in astronomy three days after the teaching sessions.

Materials and coding

First, each child was asked: "What is the shape of the earth where all people live?" As mentioned, only those children who answered that the earth was round (sphere, ball-like, circular) were included into the study.

The understanding of *gravity* (as a domain-specific verbal knowledge) was assessed by the question: "Why would the stone thrown up fall down again?" The answers were divided into two categories: 1) explanations using the concept of attraction - gravity (e.g. the earth pulls it back) (higher level) and 2) others (including characteristics of the stone and anthropocentric answers).

The rest of the astronomical knowledge was assessed by drawing tasks. We used these tasks to assess the knowledge because these were not used in any teaching lessons. Children were given an A4-size paper and asked (cf. Baxter, 1995; Sharp, 1996; Vosniadou & Brewer, 1992) to draw 1) the earth where all people live, 2) people everywhere they live, 3) clouds everywhere they may be and 4) rain coming from these clouds. Basing on the earlier developmental studies, we used two features of drawings to show the level of astronomy knowledge. *Position* indicates if people and clouds are drawn on the 'top half' of the circle (lower level) or everywhere (higher level). *Up-down direction* shows if people and clouds/rain are aligned toward the edge of the paper (lower level) or either in a mixed way or toward the circumference (higher level). We included the drawings with mixed alignment into the higher level because it is very difficult to show objects on a sphere and even older children do not align toward the circumference only.

The number of correct answers was summed to show the total astronomy knowledge. The internal reliability of the scale was high (α=.87 in Pre-test and α=.86 in Post-test).

Results

The analyses of total scores

The means and standard deviations of the continuous variables are given in Table 1. There were no statistically significant differences in astronomy knowledge between experimental and control groups of the same age children before the teaching experiment except between model-based and verbal groups of 5-year old children. Astronomy knowledge of the 5- and the 7-year old children was significantly different both before and after teaching. Also, differences between experimental and control groups' astronomy knowledge after teaching sessions were significant.

Table 1. Means and standard deviations (in parentheses) within various groups

	Astronomy Pre-test				Astronomy Post-test			
Group	5-year olds	7-year olds	T	p	5-year olds	7-year olds	T	p

Model-based	.94 (.99)	3.16 (1.42)	5.44	.001	2.61 (2.03)	4.11 (.99)	2.90	.007
Verbal	1.88 (.92)	2.39 (.92)	1.62	.11	2.41 (1.06)	3.90 (1.08)	4.1	.001
Control	1.00 (1.76)	2.63 (1.82)	3.00	.006	1.33 (1.72)	3.32 (1.20)	3.80	.001
Total	1.30 (1.27)	2.73 (1.26)	5.70	.001	2.12 (1.70)	3.77 (2.28)	5.50	.001

Analysis of Covariance was performed with the Post-test astronomy score as a dependent variable, the instruction group (model-based, verbal and control) and age (5-and 7-year olds) as independent variables and Pre-test score as a covariate. Significant main effects of instruction F(2,96)= 4.74, p=.01 and age F(1,96)= 8.91, p=.004 on the Post-test astronomy score were found. However, the instruction x age interaction was not significant (F (2,96)=1.52, p=.22). Older children's total score was higher than the younger ones', and both experimental groups did better on Post-test (see Figure 1). The accompanying regression results showed that the Pre-test astronomy score accounted for 25% of the within-group variability (F(1,96) = 32.01, p<.0001).

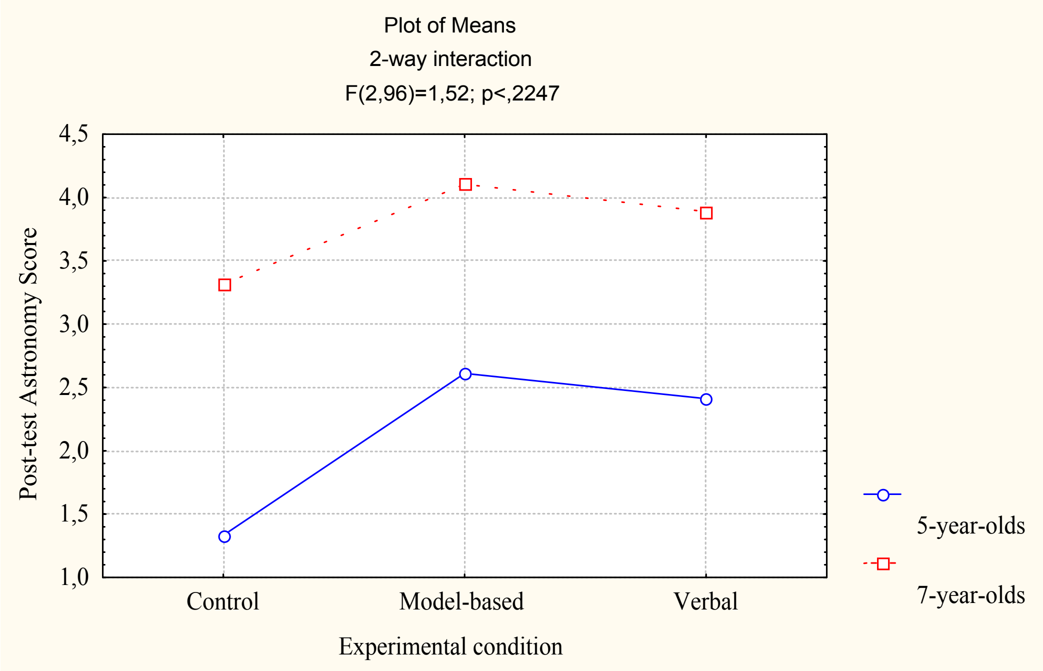

Figure 1. Post-test Astronomy score as a function of experimental condition and age (with Pre-test Astronomy Score as a covariate)

As expected, the astronomy Pre- and Post-tests were significantly correlated with each other (r=.61, p<.001 for all the groups; r=.54, p<.001 for 5-year olds and r=.43, p<.001 for 7-year olds). We also conducted multiple-regression analysis for the astronomy Post-test, using age, gender, experimental condition (dummy coded) and astronomy Pre-test score as predictors. The best predictors of the performance on the Post-test were Pre-test score, age and no-teaching (i.e. control) condition (see Table 2). The model described about 46% of variation in the Post-test scores.

Table 2. Multiple regression results (N=103) for the Astronomy post-test score (total R^2=.46; F(3,99)=28.027 p<.001)

Variable	Beta	Sebeta	B	SEB	t (99)	p
Astronomy Pre-test	.45	.09	.50	.10	5.10	<.001
Age	.28	.09	.03	.01	3.20	<.001
Control group	-.21	.07	-.74	.26	-2.83	0.01

As to the separate tasks, no between-groups differences were seen in drawing tasks. The only group which became better in gravity task was the model-based experimental one. Here, the knowledge of twelve children improved, the difference between groups was significant ($\chi^2(2)=14.9$; $p<.001$).

Difficulties in learning

The analysis of the transcriptions did not show any abrupt improvements in children's knowledge. The improvement was rather gradual, resulting for most of the children in better scores in Post-test (exceptionally, four children had worse results in Post-test). The following sources of difficulties in learning were found.

1. Everyday conception that gravity does not affect everything. Some children thought that gravity does not affect those things that are currently not connected with the earth's surface – for example flying birds and aeroplanes. During teaching we stressed that gravitational force acts between objects and in order to overcome the attraction between the earth and the object, some force must be used – birds have to flap wings and aeroplanes need engines and fuel to fly. These explanations helped children to overcome their confusion and afterwards some of them even figured out that without gravitational attraction everything would float in the air.

2. Everyday belief that the up-down direction is fixed. Several children stated that on the other side of the world people live on their heads and walk on their hands or heads. If children think that the up-down direction is fixed, they give explanations from their own perspective, meaning that when one is upside-down, ones head points toward the earth's surface and ones legs are up in the air (i.e. people live on their heads). To change that misconception, in model-condition, we used the model of the earth in addition to the verbal explanation. When we said that the people are seemingly upside-down, we placed some dolls on a ball and pointed out that from afar it seems that it is hanging upside-down, but that its feet are actually towards the earth's surface. In the end, nobody talked about people living on their heads. In verbal condition, only imaginary tasks were used.

3. Difficulties in understanding the analogy with magnetic force. We used a magnet as an analogue of the earth to explain the force of attraction because enabled to show that one needs force to pull an object away from the attracting magnet. However, this analogy also caused misunderstanding about the nature of the force of gravity. For example, one child perfectly explained that a magnet attracts metal with magnetic force. However, he did not pay attention to the important differences between the earth's gravity and magnetic force. In the following lesson he said that the earth is a big magnet, which attracts people with a magnetic force. He had formed a misconception and he maintained it through the following lessons.

Discussion

Learning scientific knowledge is different from gaining everyday knowledge. Everyday concepts develop from concrete perceptible instances, and therefore depend on their referents and contexts (Vygotsky, 1994). Learning about the world beyond senses occurs through the medium of verbal instruction. Abstract, out-of-empirics content of knowledge taught at school demands the usage of new type of psychological tools (signs); students study new type of concepts – scientific. In this sense, the words and models are both signs that mediate the knowledge that falls outside one's daily personal experience. It is difficult for young children to understand this abstract knowledge, be it be taught by verbal descriptions or using models and analogies. Therefore, it is of no surprise that no differences occurred in the efficiency of two experimental teaching conditions. The results showed that even 5- and 7-year old children's astronomy knowledge was improved due to teaching, regard of which teaching method was used. So, children can be taught only verbally (without using any schemes or models of the spherical earth); nice-looking expensive models are not always necessary.

Although the total astronomy scores improved during teaching sessions, only five children (two of them 5-year olds) showed the highest score in Post-test. So we can talk that children learned to some extent only, the majority of them did not acquire the real scientific understanding. Possibly such young children need even more sessions and repeating of the material (cf. Smith et al., 1997). We should also remind that in certain sense children were selected for the study on the basis of their preliminary astronomy knowledge. Namely, only children who verbally stated that the earth is round (but whose knowledge was not perfect) had been included into the experiment. It could be assumed that children who have the preliminary everyday idea that the earth is flat are even in bigger difficulties in learning, and need even more thorough teaching.

The strength of the verbal method was that children were engaged in imaginary tasks, which demanded maybe even more resources and activity than simple observation of the models (model-condition). As teaching was individual, the experimenter could control that each child was engaged in learning tasks (cf. the importance of motivation in learning Pintrich, 1999). In principle, children could ask questions and propose their own ideas, which occurred rarely in reality. Children followed what the experimenter said and answered but not asked questions. The difficulties occurred because children became bored from mere talking.

The strength of the model-condition was just that the sessions were lively, children were involved in observing models or carrying out tasks. However, it seems that they were less concerned with the content (about the impact of different types of illustrations in learning see Mayer, 2001). So, in certain sense, using models even disturbed learning. Even here, in small groups, children talked quite little and only some 7-year olds asked their own questions. It has been argued that in small groups the climate is more relaxed and children can make use of peers' questions and remarks (Hatano & Inagaki, 1991). Possibly these effects become more visible with older children (for differences in group work in younger and older children see Anderson, Howe, & Tolmie, 1996; Amzitia, 1996).

The teaching addressed three areas of entrenched beliefs: the shape of the earth, up-down direction and direction of the falling of objects (gravity) (Vosniadou 1994, 1996). In accordance with the earlier findings, we found that children had more difficulties with two themes: gravitational force as attraction between objects and up-down direction as relative in space (Vosniadou, 1996; Vosniadou & Brewer, 1992). Specifically, children had difficulties in understanding how it is possible to live on the other side of the earth (because people have to walk on hands or even heads). Teachers often say people are *seemingly* upside-down, but actually live just like we do up here. However, the verbal explanation is not enough to understand the up-down relativity. The use of models helped to show what the expression *seemingly* means. If explanations are given only verbally, children don't pay enough attention to that part of the explanation, which says that people are *seemingly* upside down. When they also think that the up-down direction is fixed and tend to explain things from their own perspective, meaning that when one is upside-down, his head points toward the earth's surface and ones legs are up in the air, they'll form the idea of people living on their heads. It is worth noting that there was a difference between model- and verbal- condition in the answers to the gravity question: the model-group did significantly better after learning. So here, models seem to be useful. Also, teaching should stress this aspect more deeply. Quite contrary, in ordinary textbooks in Estonia, the stress is on describing the spherical shape of the earth and how it looks like from different perspectives. Actually, children understood these differences quiet easily, and they could even give their own examples. In contrary, the relativity of up-down direction and the attraction between masses remained unclear; children were confused and afraid to give examples.

It addition, it should be stressed that one must be very careful when using analogy with so young children. In our study we used a magnet as an analogue of the earth to explain gravity. Some might say that the use of a magnet in inappropriate because the mechanisms underlying the earth's gravity and magnets ability to attract metal are different, but we think the magnet-analogy can be used when in addition to the similarities the differences between the phenomena are pointed out. If it is not done it is possible that children understand the idea, but confuse the appropriate terms and can't correctly explain what they learned. It can also lead to various misconceptions (Glynn, Duit & Thiele, 1995).

In accordance with the previous research, the study showed the importance of preliminary domain-specific knowledge in learning (e.g. Vosniadou, 1994). Even without any formal instruction, the 7-year olds' everyday knowledge was better than that of the 5-year olds. Possibly these children have watched or even read popular science books or talked about the subject with their parents. The results did not assure Maria's (1996) idea that it should be easier to teach younger children whose concepts are less resistant to change and more amenable to instruction. The teaching was effective in both age groups, however, it took time and effort (cf. Smith et al., 1997 for similar results in chemistry). Therefore, it seems quite impossible to teach for understanding in usual classroom with 30-40 children and during 1-2 lessons. As our results show, children's knowledge is improved with age and as it is *not* more difficult to teach older children, it seems to be worth waiting and starting with teaching this topic in older grades in ordinary schools.

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Appendix. Teaching sessions: aims, materials and tasks

Model-based teaching	Verbal teaching
I The apparent contradiction between the spherical shape and flat surface of the earth	
1. Demonstration of spheres of different size; observing them from different distances.	1. Imagining different size of spheres and how they the look from different distances.
<u>Materials:</u> balls of different size (Ping-Pong ball, tennis ball, big ball with diameter 120 cm), balloon, little dolls. <u>Tasks</u>: 1. Observing the convexity of the balls. 2. Talking about the possibility of falling down from different balls. 3.	<u>Questions talked about:</u> 1. Why do we talk about the round earth if we see its surface as flat? 2. Is there anything around us that could refer to the circularity of the earth? <u>Imaginary tasks</u>: 1. Imagine balls of

Observing small dolls on the balls. 4. Swelling the balloon and observing the changes in its convexity.	different size. 2. Imagine the ball so that its surface looks flat.
2. Showing the possibilities of determining the spherical shape of the earth. Materials: balls of different size (see before), little boats, lamp, pictures of the moon Tasks: 1. Showing different shapes of the shadows of the balls. 2. Observing boats sailing on the ball (what parts are seen first, where do they reach etc.). 3. Looking the pictures of different moon phases.	2. Talking about the possibilities of determining the spherical shape of the earth Questions talked about: 1. How can you prove the spherical shape of the earth? 2. How did people notice the spherical shape of the earth in old times? Imaginary tasks: 1. Imagine sailing boats from different distances. 2. Imagine people on opposite sides of the mountain - how do you see your friend coming from behind the mountain? Materials: Pictures with boats.
3. Demonstration of the relativity of the flatness of the earth. Materials: balls of different size (see before), pictures of the earth taken from outer space. Tasks: 1. Discussions, basing on children's everyday knowledge (how does the surface look like from different places on the earth, e.g. in town, in fields, near sea). 2. Looking at the ball from different distances. 3. Looking at pictures of the earth.	3. Talking and imagining the shape of the earth from different distances. Questions talked about: 1. What shape of the earth can we see and how? 2. How does the earth look like a) if standing in front of the school, b) in an airplane? Imaginary tasks: 1. Image flying in a plane. How does the earth look like when the plane takes off? 2. Getting higher - how does the earth look like?

II Gravity

1. Demonstration of the work of magnet and magnetic interaction between objects.

Materials: magnets and nails of different size and shape.

Tasks: 1. Showing the work of magnet. 2. Analysing how intensively the magnet attracts and what determines this intensity. 3. Experimenting with magnet and nails.

2. Explaining the possibility of living on the earth and the force of gravity, drawing on the analogy with magnetic force. Materials: magnets and nails (see before), balls of different weight (Ping-Pong, tennis, balloon); pictures of aeroplanes, rockets, balloons). Tasks: 1. Throwing balls of different weight and analysing the strength needed. 2. Jumping up and analysing the strength needed to jump higher vs. lower. 3. Explaining what is needed for balloons, aeroplanes and rockets to travel in space. 4. Drawing analogy with the tasks shown in the previous session (demonstrating again the magnet and nails).	3. Explaining the possibility of living on the earth and the force of gravity, drawing on the analogy with magnetic force. Questions talked about: 1. Why don't the people living on the opposite sides of the earth fall down? 2. What must we do to take off from the earth? 3. Why is it so difficult? 4. What direction does the earth pull things? 5. Drawing analogy with the tasks shown in the previous session (demonstrating again the magnet and nails).

III Up-down direction on the earth

1. Showing the relation of the up-down direction connected to the surface	2. Talking about the relation of the up-down direction connected to the

(centre) of the earth.

Materials: picture of a house with two floors (one person is standing on the ground, another person on the first floor, a mouse lives between them); globe, small ball, dolls.

Tasks: 1.The up-down position of the mouse in relation to two persons. 2. Throwing balls from different points of the globe. 3. Do Australians live upside down? Discussion with the help of the globe and doll.

3. Showing the relativity of up-down direction in cosmos.

Materials: globe, dolls, pictures of the earth from outer space, pictures of planets and the moon.

Tasks: 1. The relativity of up-down position of people on the earth as observed from outer space. 2. Does it rain upside in Australia? How do Australians see it. How does it look from outer space? 3. What does up and down mean on the moon/planets?

surface (centre) of the earth.

Questions talked about: 1. Do Australians walk upside down? 2. What does it mean - up-down, in front of, behind? 4. Does it rain from up to down everywhere around the earth?

Imaginary tasks: 1. Imagine looking at a thing from different points. 2. Image observing raining direction from different points.

3. Talking about the relativity of up-down direction in cosmos.

Questions talked about: 1. Can we speak about the up-down direction in the space? 2. What does up and down mean on the moon or on planets?

Imaginary tasks: 1. Image rain in Australia.2. Image to be on some planet - where is up and where is down? 3. Imagine being in the rocket - where is up and where is down?

Резюме

ВЛИЯНИЕ ЭКСПЕРИМЕНТАЛЬНОГО ОБУЧЕНИЯ НА ПОНЯТИЯ 5 - И 7 - ЛЕТНИХ ДЕТЕЙ О ЗЕМЛЕ И ГРАВИТАЦИИ

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Целью исследования было изучение влияния возраста и экспериментального обучения на освоение понятий о земле и гравитации. 47 ребенка из детского сада (в возрасте 60-69 месяцев) и 56 ученика первого класса (в возрасте 85-95 месяцев) были распределены на три группы: основанную на модели, вербально-индивидуальную обучающюю группу и на группу контроля. Три темы, имеющиеся целью изучать детские предварительные понятия и изменить их укоренившиеся верования, были охвачены в обучении: сферическая форма земли; гравитатция; относительность выше-нижнего направления. Результаты показали, что знания об астрономии как 5-летних так и 7-летних детей улучались благодаря обучению, не смотря на то, какой метод обучения использовался; однако, интеракция фактора возраста не было статистически существенным. Затруднения которые возникали в учения и их источники были обсуждены и выводы для обучения были зделаны.

Ключевые слова: гравитация, земля, экспериментальное обучение.

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