DISSERTATIONES PSYCHOLOGICAE UNIVERSITATIS TARTUENSIS

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**TRIIN HANNUST**

# Children's knowledge about the Earth and gravity and its change in the course of development and learning

TARTU UNIVERSITY PRESS

Department of Psychology, University of Tartu, Tartu, Estonia

Dissertation is accepted for the commencement of the degree of Doctor of Philosophy (in Psychology) on the 4th of March 2011 by the Council of the Faculty of Social Sciences and Education, University of Tartu

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Commencement: April 29, 2011

ISSN 1024–3921
ISBN 978–9949–19–612–8 (trükis)
ISBN 978–9949–19–613–5 (PDF)



Tartu Ülikooli Kirjastus
www.tyk.ee
Tellimus nr. 156

# CONTENTS

LIST OF ORIGINAL PUBLICATIONS .................... 6

1. INTRODUCTION .................... 7
   1.1. The acquisition of knowledge .................... 7
   1.2. The development and nature of non-scientific knowledge .................... 9
   1.3. The influence of assessment methods on the expression of knowledge .................... 10
   1.4. Changes in children's responses .................... 11

2. AIMS OF THE THESIS .................... 13

3. METHODS .................... 14
   3.1. Participants .................... 14
   3.2. Measures and procedure .................... 14
   3.3. Data analysis .................... 15

4. RESULTS AND DISCUSSION .................... 17
   4.1. Main results .................... 17
   4.2. General discussion .................... 20
   4.3. Limitations and strengths .................... 21
   4.4. General conclusions .................... 22

ACKNOWLEDGEMENTS .................... 24

REFERENCES .................... 25

SUMMARY IN ESTONIAN .................... 29

ORIGINAL PUBLICATIONS .................... 31

# LIST OF ORIGINAL PUBLICATIONS


I Kikas, E., Hannust, T., & Kanter, H., (2002). The influence of experimental teaching on 5- and 7-year old children's concepts of the Earth and gravity. *Journal of Baltic Science Education, 2,* 19–30.

II Hannust, T. & Kikas, E. (2007). Children's knowledge of astronomy and its change in the course of learning. *Early Childhood Research Quarterly, 22,* 89–104.

III Hannust, T & Kikas, E. (2010). Young children's acquisition of knowledge about the Earth: A longitudinal study. *Journal of Experimental Child Psychology 107,* 164–180.

IV Hannust, T & Kikas, E. Changes in children's answers to open questions about the Earth and gravity. Manuscript submitted for publication.


**Contribution of the author**

The author of the present dissertation contributed to the publications as follows:
- For **Paper I,** participating in the creation of the study design, collecting the data associated with the model-based instructional intervention, conducting the model-based intervention, participating in the analysis of data and in the writing of the paper as a co-author.
- For **Paper II,** participating in the creation of the study design, collecting the data, conducting all the data analysis, and writing the paper as the main author.
- For **Papers III** and **IV,** formulating the research questions, conducting all the data analysis and writing the papers as the main author.

# 1. INTRODUCTION

People use their knowledge about the world to solve problems, think and plan their further actions. However, not all tasks are solved successfully and not all actions are appropriate. On many instances learners' difficulties in understanding the scientific explanations of everyday phenomena have been documented (e.g., for biology, see Inagaki & Hatano, 2008; Opfer & Siegler, 2004; for physics, see Brown & Hammer, 2008; Wiser & Smith, 2008; for math, see Vamvakoussi & Vosniadou, 2004) and a lot of effort has been put into finding out how to avoid and/or overcome those difficulties (for suggestions about how to improve science instruction, see Diakidoy & Kendeou, 2001; Duit, Roth, Komorek, & Wilbers, 2001; Hatano & Inagaki, 1991; Howe, Tolmie, & Rodgers, 1992; Smith, Maclin, Grosslight, & Davis, 1997; Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001)

As elementary astronomy is one topic where learners struggle to overcome the seeming inconsistencies between their own experiences accumulated during daily living on the Earth (e.g., the seemingly flat surface of the Earth) and the taught explanations (e.g., the Earth is a sphere), the present doctoral dissertation focuses on that topic with an overall aim to examine the process involved in the acquisition and expression of knowledge. To this aim, children's answers to open-ended questions about the Earth and changes in their answers over time were studied. Special attention was paid to the influence of instruction, to the role of assessment methods, and to the methods used in data-analyses. The results are presented in **Studies I**, **II**, **III**, and **IV** that form a part of the present dissertation.

## 1.1. The acquisition of knowledge

Knowledge can broadly be divided into two categories – procedural knowledge about how to do something and declarative knowledge that contains information about something (Chi & Ohlsson, 2005). The knowledge about how to tie shoelaces is an example of procedural knowledge. Concepts, schemas, principles and theories are part of declarative knowledge (Ohlsson, 1996).

Knowledge is gained through direct action and observation of the world, as well as through indirect means like listening to verbal explanations or reading (Brewer, Chinn, & Samarapungavan, 2000; Kikas, 2003). Sometimes when there are no contradictions between new information and previously acquired concepts or theories, the acquisition of new information is relatively easy and a process called knowledge enrichment takes place – the new information is simply added to the old (Chi & Ohlsson, 2005; Piaget, 1947/2005). For example, as a result of learning, the scope of person's knowledge can increase and new connections between pieces of knowledge can appear (Chi & Ohlsson, 2005). The most important requirement for such learning to occur is the ability to remember the new information. Simple facts (e.g., the Earth is round) that later serve as basis for further knowledge development (see Vygotsky, 1934/1997) may be learnt this way.

However, in most cases knowledge is not assimilated in the ready-made form. Instead, learning only starts when learners first encounter new concepts and memorize new terms, facts, and explanations (Kikas, 2003; Vygotsky, 1934/1997). This memorized information needs to be integrated into the learners' existing conceptual system so that it can be used in understanding the world and in explaining phenomena (Brewer et al., 2000; Inagaki & Hatano, 2002; Spelke & Kinzler, 2007).

There are also instances where due to various difficulties the integration of knowledge fails. On some of those occasions learners may simply memorize facts without trying to understand the theories (Kikas, 1998). Such knowledge often becomes encapsulated, which means that the new information exists alongside previously held incorrect beliefs and that while under some conditions learners are able to give correct answers (e.g., when the situation is similar to the one where the information was acquired, see Tulving & Thomson, 1973, or when the questions are familiarly phrased), on other occasions they may give far less sophisticated answers because they are not able to generalize the knowledge (Carey, 2000; Carey & Spelke, 1994; Linn, 2008).

It is also possible that learners discard some of the new information and fall back to the safe choice of describing one's own experiences (Chi & Ohlsson, 2005), or incorrectly combine the learnt information with prior knowledge (see Albanese & Vicentini, 1997; Brewer et al., 2000; Schnotz, Vosniadou, & Carretero, 1999; Vosniadou, 1994). For example, when learning a new scientific concept, the learner may have to overcome at least some of the following problems: (i) the discussed phenomena are not directly observable, (ii) there are inconsistencies between experience-based knowledge and scientific explanations, (iii) science is mostly taught by means of verbal descriptions and by using familiar concepts in an unfamiliar way, and (iv) many of the terms used in discussing the topics are abstract and can be interpreted in various ways (Johnson & Carey, 1998; Kikas, 2003; Vygotsky, 1934/1997). In order to overcome these problems, learners' preliminary conceptual system has to be revised and reorganized and connections between verbal and experiential knowledge must be built (Brewer et al., 2000; Chi & Ohlsson, 2005; Chinn & Malhotra, 2002; Piaget, 1947/2005; Vygotsky, 1934/1997).

Furthermore, as scientific concepts replace incorrect beliefs only when the new concepts are understood, seem plausible, and are more useful than old ideas (Brewer et al., 2000), great care must be taken when providing instructions. The problem, that verbal teaching-methods which concentrate on teaching factual information and do not use experiments or demonstrations often fail to lead to the adoption of scientific concepts, has been indicated by several authors and is also discussed in **Studies I** and **II** (Carey, 1999; Carey & Spelke, 1994; Diakidoy & Kendeou, 2001; Vosniadou et al., 2001).

## 1.2. The development and nature of non-scientific knowledge

Several studies have focused on finding out whether before the adoption of scientifically accepted ideas learners construct and re-construct internally consistent mental models and theories or can their knowledge be described as consisting of independent fragments that sometimes even contradict each other. The debate has been very intensive in the field of elementary astronomy and provides arguments both for and against the idea that naive knowledge of elementary astronomy is consistent before the acquisition of scientific understanding has been reached (e.g., see Diakidoy, Vosniadou, & Hawks, 1997; Nobes et al., 2003; Samarapungavan, Vosniadou, & Brewer, 1996; Siegal, Butterworth, & Newcombe, 2004; Straatemeier, van der Maas, & Jansen, 2008; Vosniadou, 1994, 2002; Vosniadou & Brewer, 1992; Vosniadou, Skopeliti, & Ikospentaki, 2004)

The main idea of the mental models approach is that both children and adults construct an intuitive understanding or mental model of the world which is based on their own experiences of living in the world and is an analog of the perceived state of affairs that it represents (see Vosniadou & Brewer, 1992). This model is created for the purpose of answering questions and solving problems and its construction is constrained by the person's underlying conceptual structures (Vosniadou & Brewer, 1992). Therefore, if a person is confronted with new information that contradicts some of the experience-based knowledge (e.g., scientific theories taught in school) he or she can either disregard the new information or try to change the existing conceptual system to integrate the new information (Brewer et al., 2000; Chi & Ohlsson, 2005; Vosniadou 1994). The proponents of the mental-model approach believe that this process is gradual and that as a result of learners' attempts to overcome the inconsistencies between different pieces of information many intermediate steps called synthetic models or misconceptions may develop before accurate understanding is achieved (Vosniadou et al., 2004; Vonsiadou, Skopeliti, & Ikospentaki, 2005). They also believe that as the construction of synthetic models resolves the conflict between different pieces of information they may inhibit further learning because learners do not see the need to adjust their knowledge (Chinn & Brewer, 1993; Maria, 1996; Smith et al., 1997).

The idea that conceptual development can be described as the construction of intermediate models that have increasingly higher explanatory power is in accordance with the writings of Vygotsky (1934/1997) who believed that children construct two types of concepts that undergo several changes before the culturally accepted meanings are adopted. The first are spontaneous concepts that are based on concrete perceptible instances and depend on the referents. They are tied to experience and refer directly to objects but as long as the terms have no connection to other concepts and children are not conscious of them it is not possible to use them to form abstractions. Links with other pieces of knowledge have to be formed before this knowledge can be used deliberately and systematically. This process is supported by the acquisition of the second type of concepts – scientific concepts that are learnt from verbal explanations of others and therefore may in the beginning be excessively abstract and detached from reality. Scientific concepts provide the understanding that any concept can be formulated in terms of other concepts whereas the spontaneous concepts mediate the development of scientific concepts by connecting them to everyday life. Vygotsky (1934/1997) also believed that before understanding is reached children form intermediate concepts or pseudo-concepts that serve as connecting links between thinking in everyday concepts and thinking in scientific ones.

The opponents of the mental models approach can be said to be in agreement with that part of Vygotsky's theory which indicates that the development of a concept just starts when a child memorizes a new term and that scientific concepts need to be filled with meaning. They argue that in the beginning separate fragments of information that are either based on personal experience or communicated piecemeal by others, are segregated and stored separately from each other (DiSessa, 2008; Karmiloff-Smith, 1996; Nobes et al., 2003; Nobes, Martin, & Panagiotaki, 2005). These fragments become more organized over time and finally the scientific theory is acquired. However, they do not agree that before reaching scientific understanding knowledge can be described as a naive theory that is organized around some core principles.

**Studies II, III** and **IV** address the topic by examining whether children's answers indicate the presence of coherent synthetic models of the Earth.

## 1.3. The influence of assessment methods on the expression of knowledge

One reason for the strong opposition to the idea of consistent non-scientific models lies in the methods (e.g., open questions, drawings, and model-making tasks) the proponents of the mental models approach have used to assess and classify knowledge. Studies supporting the idea that children's knowledge is consistent have used open-ended questions and have asked children to draw or make a model that depicts the Earth (see Vosniadou & Brewer, 1992, Vonsiadou et al., 2004, 2005) whereas supporters of the fragmentation approach have presented children with a pre-made model, gave clues about the correct perspective from which one is expected to view the objects under discussion, or have used methods that require children to select the answer form a list (see Nobes & Panagiotaki, 2007, 2009; Nobes et al., 2003, 2005; Schoultz, Säljö, & Wyndhamn, 2001; Siegal et al., 2004; Straatemeier et al., 2008).

The comparisons of results produced by different methods have indicated that on one hand some of the previously used open questions themselves already imply a certain model of thinking and on the other hand people often misinterpret some of the tasks and therefore, often fail to express their knowledge accurately (Nobes & Panagiotaki, 2007; Panagiotaki, Nobes, & Banerjee, 2006; Panagiotaki, Nobes, & Potton, 2009; Schoultz et al., 2001).

Another line of criticism is directed at the methods Vosniadou and Brewer (1992) used to identify mental models. They examined the data for coherent patterns of responses that denote mental models but later when inconsistencies in children's answers were found, the mental models were modified to allow for those. Nobes and colleagues (2005) believed that the procedure discarded the possibility that those inconsistencies might have resulted from children's fragmented knowledge and showed that when no alterations are allowed, non-scientific knowledge seems to be fragmented. These and similar conflicting results led to the suggestion of Panagiotaki and colleagues (2006) that in addition to examining the answers for patterns that might denote mental models, the possibility that those patterns emerge as a result of chance should also be examined, which is done in **Studies II**, **III, and IV**.

## 1.4. Changes in children's responses

Several studies have shown that when presented with forced-choice questions or allowed to use a model as an anchor, even small children display a significantly better understanding of elementary astronomy than previously shown (see Panagiotaki et al., 2006; Schoultz et al., 2001; Siegal et al., 2004). These findings indicate that the open-ended questions used by Vosniaou and Brewer (1992) might lead researchers to underestimate children's knowledge but they do not undermine the idea that changes in answers provided to those types of questions still provide information about children's abilities to solve problems.

Already in the beginning of the 20$^{th}$ century, the idea that the reasoning ability develops was stressed and children's knowledge about different natural phenomena was studied. It was proposed that during a certain period children are only able to focus on the most dominant features of a task and only later will progress to include all relevant aspects that allow them to solve problems correctly (Inhelder & Piaget, 1955/1958).

More contemporary studies have shown that the ability to progress to more advanced stages of problem solving might be reached at an earlier age than previously believed. However, all in all the results are in agreement with the idea that at some point task dominant feature may inhibit the solving process. For example, studies examining problem-solving in class-inclusion tasks, math, and physics have revealed that when children are confronted with unfamiliar tasks that include one perceptually salient feature they indeed often tend to rely on this single dimension and only use one rule (Siegler & Chen, 2002; Siegler & Svetina, 2006). Only when learners are presented with relevant learning experiences can they adopt new and more advanced ways of solving problems and a sufficiently large knowledge-base allows them to further generalize the existing knowledge and therefore apply it in new areas (Halford, Andrews, Dalton, Boag, & Zielinski, 2002; Ohlsson, 1996). Still, though some learners adopt the most advanced methods of problem solving right away, others oscillate between correct and incorrect approaches, and a few even abandon previously used strategies (e.g., Siegler & Svetina, 2006) which indicates that in addition to learning experiences other factors might influence the process. **Studies III** and **IV** examined problem solving in elementary astronomy and investigated the role of topic-related knowledge in those processes.

# 2. AIMS OF THE THESIS

The overall aim of the current dissertation was to study conceptual change in elementary astronomy by examining how children express their knowledge in response to open questions about the Earth and gravity. The topic of astronomy was chosen because the nature of children's non-scientific knowledge of astronomy has been under a lot of debate in recent years and different researchers have expressed opposing opinions about the consistency of that knowledge (e.g., see Nobes & Panagiotaki, 2009; Panagiotaki et al., 2009; Vosniadou & Brewer, 1992; Vosniadou et al., 2004; Vosniadou, Skopeliti, & Ikospentaki, 2005).

The specific objectives were formulated as follows:

**Study I** aimed to study children's everyday astronomy concepts about the Earth and gravity and the influence of two different experimental teaching methods on the change of expressed knowledge.

**Study II** examined children's knowledge of elementary astronomy before and after an instructional intervention to see whether their answers indicate the presence of consistent models of the Earth before teaching, to analyze the influence of instruction on the expressed of knowledge, and to find out what kind of information is easier to understand for young children.

To make sure that no major stages in the development of knowledge (e.g., the construction of intermediate non-scientific models) are missed, young children's expressed knowledge of astronomy was examined in two studies. In **Study III** the initial knowledge of 2- to 3-year olds was examined and followed during the next 3-years. In **Study IV** first graders' knowledge was assessed directly after initial instruction and also re-assessed during the following tree years. In both studies two different types of analysis (manual search and the Configural Frequency Analysis / CFA) were used to examine whether any patterns indicating the presence of consistent non-scientific mental models could be found and whether those combinations appeared more often than could be expected by chance.

**Studies III** and **IV** both also analyzed whether children use similar types of answers over longer periods of time and examined the idea that only when learners have sufficient information and are confident in the correctness of the acquired factual knowledge will they be able to choose the global perspective and start providing answers that go beyond the immediately visible world.

Additionally, **Study IV** examined the idea that synthetic answers appear mainly after the topic of astronomy had been taught in school, and that their usage declines afterwards as scientific theories replace the incorrect notions.

# 3. METHODS

## 3.1. Participants

In **Study I** the data of 103 children (47 kindergarteners in the age range of 60–69 months and 56 first graders in the age range of 85–95 months) was analyzed.

Children were randomly assigned into two experimental groups. Thirty-seven children (18 kindergarteners and 19 first graders) received model-based teaching and 35 children (17 kindergarteners and 18 first graders) verbal individual teaching. Thirty-one children (12 kindergarteners and 19 first graders) who attended classes different from the experimental groups acted as controls.

In **Study II** the data of the same five and seven-year old children who comprised the model-based teaching group in **Study I** was used. Additional data of 22 six-year-olds (age 72–84 months) and that from a different control group, which consisted of 20 seven-year-olds, 17 six-year-olds, and 16 five-year-olds, was included in the analyses.

In order to examine the role of preliminary knowledge in learning, and to differentiate between the effects of age and pre-existing knowledge, in **Study II** different selection criteria were used for five- and seven-year-olds versus six-year-olds. Namely, all the selected five- and seven-year-olds were required to express the knowledge that the Earth was round or spherical, whereas none of the selected six-year-olds were required to do so.

**Study III** analyzed the data of 143 children who were 2 or 3 years old during the first assessment and who were assessed four times with one-year intervals. In **Study IV** the data of 159 children who attended the first grade of elementary school during the first assessment (and who were also assessed four times with one-year intervals) was examined.

All participants included in **Studies I**, **II**, **III**, and **IV** were Estonian-speaking children who attended regular kindergartens and schools that serve families of the second largest town in Estonia and the surrounding areas. None of the kindergarteners had officially studied the topic of elementary astronomy. The same applied to those seven-year olds whose data was analyzed in **Studies I** and **II.** Those first-graders whose knowledge was examined in **Study IV** had recently learnt about the Earth and gravity.

## 3.2. Measures and procedure

In **Studies II**, **III**, and **IV** four open questions requiring verbal answers were followed by a drawing task in which children were given a letter- size sheet of paper and pencil and were asked to draw a picture according to instructions (cf. Vosniadou et al., 2004). In **Paper I** only the drawings and answers to the first question about the shape of the Earth and to the fourth one about the effect of gravity on falling objects (see below) were analyzed.

According to Vosniadou and Brewer (1992), the questions and tasks should assess children's exposure to certain facts and their ability to generate ideas about the phenomena that cannot be directly observed. However, as the vagueness of original questions (see Vosniadou & Brewer, 1992) has been criticized, the questions were formulated so that they indicate more clearly the need to take the global perspective when answering (Nobes & Panagiotaki, 2007; Panagiotaki et al., 2009).

The questions were presented in the following order. First, "What is the shape of the Earth where all people live?" Second, "If you started walking or riding a car/train/airplane across the land in one direction and continued going in the same direction for many days, where would you end up?" Third, "Is it possible to fall off the Earth?" followed by "From where could you fall off to?" (if the answer to the first question had been positive) or "Why not?" (if the first answer had been negative). Fourth, "Why does a ball (the word stone was used in **Study I** instead of ball) that has been thrown up fall down again?" was asked to see whether children were familiar with the concept of gravity.

In the drawing tasks, children were given instructions in the following order. First, "Draw the Earth where all people live." Second, "Draw people on the Earth; draw some everywhere where they might be." Third, "Draw clouds on the picture; draw them where they might be." Fourth, "Draw the rain falling from the clouds." Finally, to clarify the meaning of the term "round," children were shown a ping-pong ball and a similar-sized disc and were asked, "You said the Earth was round. Did you mean round like a ball or round like a disc?" These models were shown to children after the completion of the drawing tasks so that the objects would not influence the answers given to previous questions (cf. Schoultz et al., 2001; Vosniadou et al., 2004, 2005). In all assessments the interviews with children of consenting parents were conducted in a separate room in kindergarten or school. A single person (though not all children were interviewed by the same person), who wrote down and recorded all the child's utterances, interviewed each child.

In **Studies I** and **II** the initial interview was followed by short lessons on the topic of elementary astronomy and a post-learning assessment. In the verbal individual teaching condition, the teacher explained the material verbally to individual children and in the model-based teaching sessions small groups (2–3 children) could experiment with provided materials under the supervision of the teacher.

In **Studies III** and **IV** the same questions were asked four times with 1-year intervals between sessions.

## 3.3. Data analysis

In **Study I** differences between experimental and control groups as well as between different age-groups were analyzed with t-test. Analysis of covariance was performed with the astronomy score received after instruction as a dependent variable, the instruction group and age as independent variables, and Pre-test score as a covariate.

Both in **Studies I** and **II** qualitative analysis of the transcriptions of teaching-sessions was conducted to examine the influence of instruction. In **Study II** Kruskal–Wallis ANOVA was used to compare the amount of expressed knowledge of astronomy before and after instruction in experimental and control group and the Sign test was used to investigate the changes within groups.

Cochran's Q-test was used to compare correct answers provided to each question before and after instruction in **Study II** and to compare the proportions of specific types of answers (no answer, description of the world, synthetic answer, scientific answer) given in response to the same question during different assessments in **Study III**.

In order to find out whether children's knowledge is organized into consistent non-scientific models, in **Studies II**, **III, and IV** the following procedure was used. First, combinations of answers that describe consistent models (similar to those proposed by Vosniadou & Brewer, 1992) were specified and the data set was manually searched for those models. Second, Configural Frequency Analysis (CFA), which uses the exact binomial test, was conducted to see whether any combinations of answers (including those patterns that denote consistent models) occur more often (type) or less often (antitype) than expected on the basis of a chance model (von Eye, 1990, 2001). Alpha levels were adjusted with Bonferroni's procedure. For that end the CFA module of the SLEIPNER 2.1 program (see. Bergman, Magnusson, & El-Khouri, 2003) was used.

In **Study III,** CFA was also used to i) examine at the individual level how answers provided in response to the same question change over the course of four years, ii) to see whether the amount of expressed knowledge of facts is related to the nature of knowledge expressed when answering generative questions, and iii) to find out whether the answers given during an earlier assessment are related to the responses given during the following year.

To examine changes in schoolchildren's answers in **Study IV,** Repeated-Measures ANOVAs were carried out with the following knowledge scores: number of factual answers, number of descriptions, number of incorrect generalizations, and number of scientifically accurate answers as dependent variables. Post-hoc analyses were done with the Bonferroni correction. Additionally, CFA was used to find out whether the answers children give when responding to generative questions depend on their expressed knowledge of facts.

Also, to get a more thorough overview of the development of knowledge two (group: kindergarten and school) x four (time of testing) Repeated-Measures ANOVAs with both kindergarteners' and schoolchildren's factual knowledge scores, descriptions, synthetic, and scientific astronomy scores as dependent variables as well as separate analyses in kindergarten and school groups were conducted and the results are presented in the thesis.

# 4. RESULTS AND DISCUSSION

## 4.1. Main results

The present analysis showed that as a result of both direct and indirect instruction, children start to express more accurate knowledge about the Earth and gravity and that before children are able to give answers that are in accordance with the scientific theories their answers are mostly fragmented. However, the results also showed that some children indeed seem to struggle with understanding and may express incorrect ideas instead of providing scientifically accurate answers. Furthermore, the analysis of transcripts described in **Studies I** and **II** indicated that sometimes methods used in instruction lead to the adoption of incorrect explanations.

Though there have been indications that traditional verbal teaching methods might be insufficient to help children understand scientific concepts and theories (see Diakidoy & Kendeou, 2001; Kikas, 1998; Vosinaodu et al., 2001), the results of **Study I** indicated that age as well as both the model based and the purely verbal instruction had a positive effect on children's expressed knowledge and indicated that when compared to purely verbal instruction the model-based approach had a superior effect only on children's ability to understand the gravity-task. **Figure 1** is based on the data of **Study I** and illustrates the changes in children's knowledge scores as a function of age and instruction.

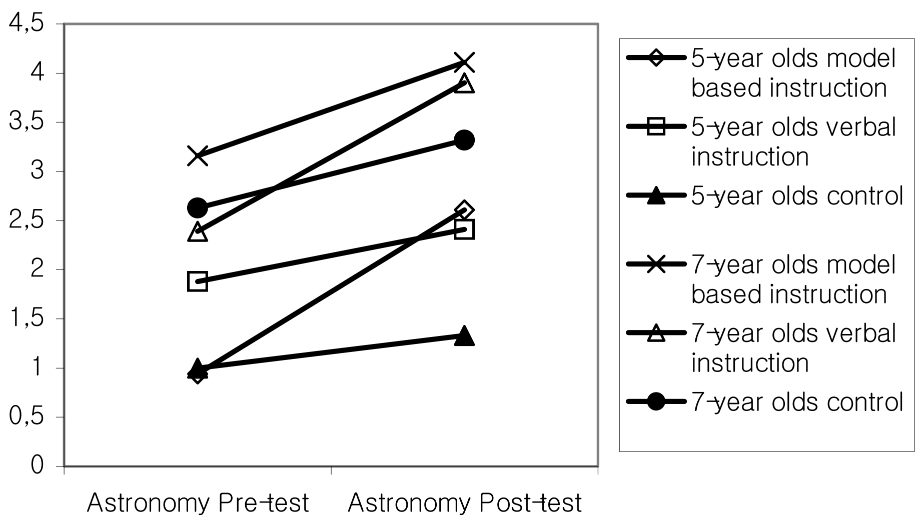


**Figure 1.** Children's mean astronomy scores before and after instructional intervention

The examination of changes in children's answers in **Study II** showed that both children with some expressed preliminary knowledge as well as those who did not know the basic facts about Earth and gravity profited from model based instruction – after instruction children used descriptions and synthetic answers less often and gave accurate answers more often that the control group. When compared to their own Pre-instruction scores the experimental group avoided answering or described only their visible surroundings less often and had a higher score of accurately expressed knowledge.

The analysis of the consistency of children's answers in **Study II** showed that in most cases children's expressed non-scientific knowledge is fragmented. For example, in **Study II** the percentage of children whose answers seemed to indicate the presence of a synthetic model was low both before (about 10 %) and after (about 15 %) instruction and CFA showed that only the pattern indicating the scientifically accurate model could not be attributable to chance. Similar results were found in **Studies III** and **IV**. In **Study III** the manual search for synthetic models showed that the highest percentage (23%) of non-scientific models was identified during the final assessment but CFA indicated that only 20 cases from those could not be attributed to chance. In **Study IV t**he initial search showed that after formal instruction the percentage of non-scientific models vas even higher, but CFA revealed that only two patterns in the fourth grade (21% of the participants were classified as having a scientifically accurate model of the Earth and 30 % gave answers consistent with the Hollow Earth mode) appeared above chance levels. These results support the fragmentation approach and the idea that most consistent non-scientific models might be the result of random combinations of actually unrelated answers (Nobes et al. 2003, 2005; Siegal et al., 2004; Panagiotaki et al., 2009; Straatemeier et al., 2008)

Analyses of individual questions performed in **Study III** showed that the proportion of children providing correct answers was highest for the question about the shape of the Earth and second highest for the question about the possibility of falling from the Earth. For most questions the proportion of children providing accurate answers increased with each assessment and the number of those who did not respond decreased. CFA showed that answers given to the same question during four different assessments were not related.

**In Study III** the examination of relations between expressed knowledge of facts and answers provided in response to generative questions showed that children who did not answer any of the factual questions correctly were also unable to take the more global perspective and only described the visible world. **Study IV** additionally showed that in elementary school children with less than a perfect score of expressed knowledge tended to use of synthetic answers more often and that a perfect score of expressed factual knowledge was related to the use of scientific explanations.

To get a better overview of the effect formal schooling has on children's ability to express their topic-related knowledge we compared the elementary school children's data described in **Study IV** to the kindergarteners' data used in **Study III.** The mean scores illustrating the kindergarteners' and schoolchildren's expressed knowledge of astronomy during the four consecutive assessments are presented on **Figure 2.**

The results of the Repeated-Measures ANOVAs showed that both the effects of group and assessment time as well as their interaction were significant for all variables, $p < .001$. Schoolchildren's factual knowledge scores, synthetic knowledge scores, and scientific knowledge scores where higher and their mean descriptions score was lower than the respective scores in kindergarten. As all the interactions were significant, we next carried out separate analyses in kindergarten and school groups. Post-hoc analyses were done with Sheffé test, and only significant results are reported.

Factual knowledge scores improved steadily both in kindergarten, $F(3, 426) = 80.70$, $p < .01$, and in school, $F(3, 474) = 49.99$, $p < .01$. Similarly, scientific knowledge scores improved steadily in kindergarten, $F(3, 426) = 3.91$, $p = .01$, and in school, $F(3, 474) = 112.46$, $p < .01$ with each passing year.

Description scores increased in kindergarten during the first three assessments and then started decreasing, $F(3, 426) = 10.11$, $p<.01$. The differences were significant between the first and the second, the first and the third, and third and the fourth assessment. In school the changes in descriptions were also significant, $F(3, 474) = 63.68$, $p < .01$, during the first two assessments children used descriptions significantly more often than during the last two assessments.

Synthetic knowledge scores increased in kindergarten, $F(3, 426) = 53.43$, $p < .01$, and differences were significant between the first and second but also third and fourth time points. In contrast, in school the first graders mean score of synthetic knowledge of was higher than in the second, third, and fourth grade, $F(3, 474) = 132.94$, $p < .01$.

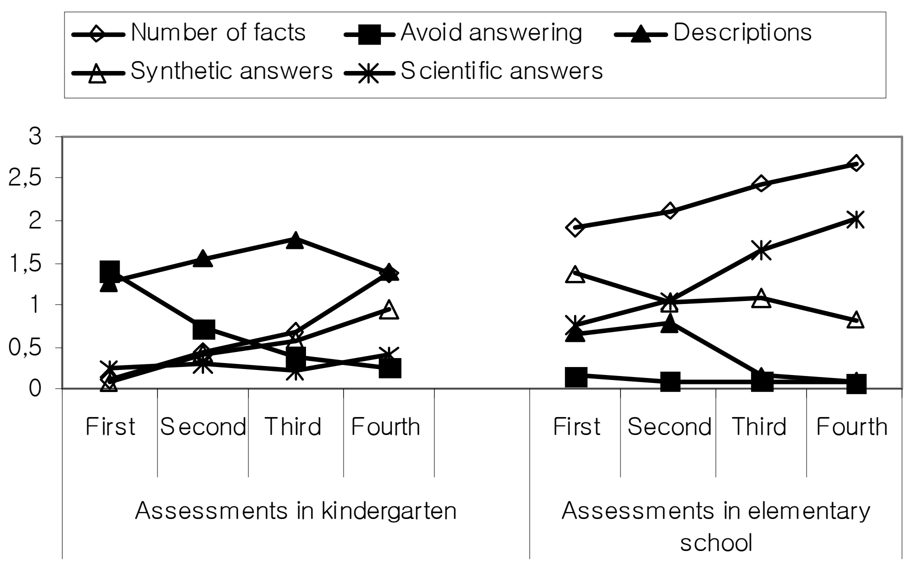


**Figure 2.** Kindergarteners' and schoolchildren's expressed knowledge of astronomy

## 4.2. General discussion

Previous studies examining knowledge acquisition have indicated that although people's knowledge changes constantly, when left to their own devices learners may be unable to overcome the seeming conflict between experience-based knowledge (e.g., it is uncomfortable to hang upside-down) and scientifically proven information (e.g., people can live on the other side of the Earth without any discomfort). Most often the inappropriateness of verbal instruction methods that lead to rote learning and pure memorization of information without understanding has been indicated as a source of difficulties (e.g., Kikas, 1998). However, it seems that some of the former criticism might have been too harsh and that both purely verbal and mode-based instruction methods can increase the amount of accurately expressed knowledge (see **Study I**). Still, there were also indications that some topics (e.g., the topic of gravity in **Study I**) indeed might benefit more from model-based instruction (cf. Diakidoy & Kendeou, 2001; Hatano & Inagaki, 1991; Howe, Tolmie, & Rodgers, 1992; Smith et al., 1997; Vosniadou et al., 2001) and it seems that sometimes poor wording of explanations or some very distinct (but not relevant) features of the models used in instruction might increase the amount of incorrect knowledge and perhaps lead to the expression of synthetic ideas (see **Studies I, II,** and **IV,** also cf. Kikas, 1998).

The idea that preliminary knowledge plays an important role in learning has also been of interest to scientists and several earlier studies have indicated the hindering effect of incomplete preliminary knowledge (cf. Maria, 1996; Linn, 2008; Vosniadou, 1994). However, contrary to these earlier findings the present studies showed that even if children know only a few isolated facts, those facts promote rather than disrupt the acquisition of further knowledge. For example, it was found (**Study I**) that children with better preliminary knowledge profited more from instruction than those who expressed lower amounts of pre-existing knowledge and that children who gave almost no correct answers before teaching seemed to become confused by the instruction and discarded all of the learnt material rather easily (**Study II).**

DiSessa (2008) has written that in order to learn a concept, the fragmented pieces of information (some of which are based on direct experiences) associated with that concept have to be coordinated and re-contextualized. Vygotsky (1934/1997) also believed that scientific concepts are based on everyday concepts but develop so that they encompass more than the immediate experiences. When these ideas are considered together with the idea that one of the perquisites for knowledge development is the awareness of one's own preliminary knowledge (Vosniadou, 1996), then the present results might simply mean that children with higher amounts of expressed knowledge were further along the path of integrating personal experiences with verbal information and therefore benefited more from instruction than those who had not even thought about the topic previous to the assessment.

Another issue examined in the present dissertation was the question about the nature of and changes in learner's knowledge before the acquisition of scientific concepts. The analyses (**Studies I**, **III**, and **IV**) showed that when vague open questions which provide almost no clues about the correct answers are used in knowledge assessment, respondents indeed sometimes produce answers where personal experience seems to be incorrectly synthesized with learnt factual information (cf. Vosniadou & Brewer, Vosniadou et al., 2004; 2005). Furthermore, the ability to take the global perspective instead of merely describing ones surroundings which was indicated by the emergence of both synthetic and scientific answers co-occurred with higher amounts of expressed factual knowledge, which is in accordance with the idea that synthetic ideas might be an intermediate step in concept development (see **Studies III** and **IV**, also cf. Vonsiadou et al., 2004, 2005; Vygotsky, 1934/1997).

However, the occurrence rate of consistent non-scientific models found in the present studies (**Studies II, III, and IV)** was much lower than reported by Vosniadou and her colleagues (e.g., Vosniadou & Brewer, 1992; Vosniadou et al., 2004) and confirmed that before scientific understanding most children's knowledge was fragmented (cf. Nobes et al., 2003, 2005; Panagiotaki et al., 2006, 2009; Straatemeier et al., 2008). These findings also disproved the idea that when open questions are used to assess knowledge, most children are found to construct consistent synthetic models of the Earth, and instead indicated that even seemingly coherent sets of answers might actually be attributable to chance (cf. Nobes et al., 2003, 2005; Straatemeier et al., 2008; Vosniadou, 1994; Vosniadou & Brewer, 1992; Vosniadou et al., 2004).

## 4.3. Limitations and strengths

The limitations of the present studies pertain primarily to the methods used to assess and instruct children.

First, as there is a great variance in the instructional practices different teachers use and not all of those practices have the same impact on students' success (see Uibu, Kikas, & Tropp, 2010), the effect of teachers on learning must be considered. In order to minimize such influences, in **Study I** very clear instructions about the topics, instructional activities, and materials were used. Still, as in **Study I** two different persons conducted the different instructional interventions and in **Studies III** and **IV** the number of people who might have provided children with topic-related information between the assessments (and therefore the number of instructional approaches as well) is even greater, the difference in instruction might have influenced the present results and should probably be controlled in further studies.

Second, many of the criticisms regarding the use of drawings and open questions in previous studies (e.g., Diakidoy et al., 1997; Vonsiadou & Brewer, 1992; Vosniadou et al., 2004) also concern the current thesis. For example, there have been indications that tasks similar to the ones used by Vosniadou &

Brewer (1992) might be ambiguous and because of that respondents fail to express their knowledge (Nobes & Panagiotaki, 2007; Panagiotaki et al., 2006, 2009). Also, the possibility that children's pictures show the learnt routine of drawing the Earth instead of their beliefs or that children might have drawn non-scientific models because those are easier to represent on paper has been pointed out (cf. Nobes et al., 2003; Siegal et al., 2004). These criticisms point to the fact that the current studies might indeed have underestimated the level of children's knowledge – a fact that has been taken into account in interpreting the results.

However, the use of these ambiguous tasks can be considered as strength of the present studies as well. It allowed to examine whether the presence or absence of consistent non-scientific models was related to the methods used in assessment as indicated previously (see Brewer, 2008; Nobes et al., 2003, 2005; Panagiotaki et al., 2006; Siegal & Surian, 2004; Siegal et al., 2004 Straatemeier et al., 2008; Vosniadou et al., 2004) and confirmed (see **Studies II, III, and IV**) that in most cases the patterns that denote mental models are the result of chance (cf. Panagiotaki et al. 2006).

Another strength of the thesis is connected to the fact that in addition to cross sectional comparison that mainly provides information about the examined persons' current state of knowledge, both the microgenetic method (**Studies I** and **II**) which allows to follow and describe the changes in competence while they occur (see Siegal & Svetina, 2006), and the longitudinal method (**Studies III** and **IV**) which helps map the more long-term changes in understanding and reveal much about conceptual development (see White & Gunstone, 2008) were used.

## 4.4. General conclusions

In order to instruct and assess learners' knowledge accurately, information about how people learn and how they express their knowledge is needed. Understanding how scientific knowledge is acquired is especially important because studies prove that people (both adults and children) often find it difficult to come up with a correct answer when faced with questions that require the application of scientific theories (e.g., McCloskey, 1983; Inagaki & Hatano, 2008; Opfer & Siegler, 2004; Wiser & Smith, 2008). The purpose of the present collection of studies was to investigate the reasons for those difficulties by examining the change in and expression of learners' knowledge on the potentially difficult topic of elementary astronomy.

The studies showed that knowledge development in elementary astronomy proceeds along similar lines as in other areas (e.g., for mathematics and simple physics see Siegelr & Chen, 1998, 2002; Siegler & Svetina, 2006). Most children seem to base their initial answers on their own experience and while afterwards some of them proceed by constructing intermediate solutions for the tasks (e.g., synthetic ideas), others do not use a consistent scheme for answering for a while or adopt the scientifically accurate explanations straight away. Still, the present results also suggest that the occurrence of coherent synthetic models is very rare and often even the identified instances might be the result of chance combinations of answers or direct results of lapses in instruction. It seems that if instruction is to have an effect, educators should concentrate more on the appropriateness of their instruction methods and on making sure that the learners do not acquire misconceptions during learning and worry less about the possibility that learner's pre-existing knowledge is organized into coherent theories that resist change.

# ACKNOWLEDGEMENTS

I am very grateful to many people without whom the completion of this dissertation would not have been possible and I would like to thank all of them. First, I would like to thank my supervisor Professor Eve Kikas, whose seemingly endless patience and willingness to discuss my ideas together with her own invaluable contributions as co-author have been crucial in the compilation of this dissertation.

My special thanks goes to all the teachers and children of the kindergartens and schools who took part in these studies and made the research possible and to Berk Vaher, Clare Jonas, and Leelo Jõulu for their help with improving the language of the texts.

I am eternally grateful to my friends, family, and colleagues whose advice and support were invaluable in writing this thesis. You also made sure that I took part of activities outside the domain of science, which helped me clear my head and come up with new good ideas.

Over the years, my dissertation has received the support from the Estonian Science Foundation (grants 5371 and 7388).

# REFERENCES


Albanese, A., & Vicentini, M. (1997). Why do we believe that an atom is colourless? Reflections about the teaching of the particle model. Science and Education, 6, 251–261.

Bergman, L. R., Magnusson, D., & El Khouri, B. M. (2003). Studying individual development in an interindividual context: A person oriented approach. Mahwah, NJ: Lawrence Erlbaum.

Brewer, W. F., Chinn, C. A., & Samarapungavan, A. (2000). Explanation in scientists and children. In F. C. Keil & R. A. Wilson (Eds.), Explanation and cognition (pp. 279–323). Cambridge, MA: MIT Press.

Brown, D. E., & Hammer, D. (2008). Conceptual change in physics. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 127–154). New York: Routledge.

Carey, S. (1999). Sources of conceptual change. In E. K. Scholnick, K. Nelson, S. A. Gelman & P. H. Miller (Eds.) *Conceptual development. Piaget's legacy* (pp. 293–326). Mahwah, New Jersey: Erlbaum.

Carey, S. (2000). Science education as conceptual change. *Journal of Applied Developmental Psychology*, *21*, 13–19.

Carey, S., & Spelke, E. (1994). Domain-specific knowledge and conceptual change. In L. A. Hirschfeld & S. A. Gelman (Eds.) *Mapping the mind: Domain specificity in cognition & culture* (pp. 169–199). New York: Cambridge University Press.

Chi, M., & Ohlsson, S. (2005). Complex declarative learning. In K. J. Holyoak & R. G. Morrison (Eds.), Cambridge handbook of thinking and reasoning (pp. 371–399). New York: Cambridge University Press.

Chinn, C. A., & Brewer, W. F. (1993). The role of anomalos data in knowledge acquisition: a theoretical framework and implications for science instruction. *Review of Educational Research*, 63, 1–49.

Chinn, C. A., & Malhotra, B. A. (2002). Children's responses to anomalous scientific data: How is conceptual change impeded? *Journal of Educational Psychology, 94,* 327–343.

Diakidoy, I. A. N., & Kendeou, P. (2001). Facilitating conceptual change in astronomy: A comparison of the effectiveness of two instructional approaches. *Learning and Instruction*, *11*, 1–20.

Diakidoy, I. A., Vosniadou, S., & Hawks, J. D. (1997). Conceptual change in astronomy: Models of the Earth and of the day/night cycle in American-Indian children. *European Journal of Psychology of Education*, *12*, 159–184

DiSessa, A. (2008). A bird's-eye view of the "pieces" vs. "coherence" controversy (from the "pieces" side of the fence). In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 35–60). NY: Routledge.

Duit, R., Roth, W.-M., Komorek, M., & Wilbers, J. (2001). Fostering conceptual change by analogies—between Scylla and Charybdis. *Learning and Instruction*, *11*, 283–303.

Halford, G. S., Andrews, G., Dalton, C., Boag, C., & Zielinski, T. (2002). Young children's performance on the balance scale: The influence of relational complexity. *Journal of Experimental Child Psychology*, *81,* 417–445.

Hatano, G., & Inagaki, K. (1991). Sharing cognition through collective comprehension activity. In L. B. Resnick, J. M. Levine, & S. D. Teasley (Eds.), *Perspectives on* *socially shared cognition* (pp. 331–348). Washington, DC: American Psychological Association.

Howe, C., Tolmie, T., & Rodgers, C. (1992). The acquisition of conceptual knowledge in science by primary school children: Group interaction and the understanding of motion down an incline. *British Journal of Developmental Psychology*, *10*, 113–130.

Inagaki, K., & Hatano, G. (2002). Young children's naïve thinking about the biological world. New York: Psychology Press.

Inagaki, K., & Hatano, G. (2008). Conceptual change in naïve biology. In S. Vosniadou (Ed.), International handbook of research on conceptual change (pp. 240–262). New York: Routledge.

Inhelder, B. & Piaget, J. (1958). *The Growth of Logical Thinking from Childhood to Adolescence*. Routledge & Kegan Paul, London. (Original work published in 1955).

Johnson, S. C., & Carey, S. (1998). Knowledge enrichment and conceptual change in folkbiology: Evidence from Williams syndrome. *Cognitive Psychology, 37*, 156–200.

Karmiloff-Smith, A (1996). *Beyond Modularity: A Developmental Perspective on Cognitive Science*. Cambridge, MA: MIT Press.

Kikas, E. (1998). Pupils' explanations of seasonal changes: Age differences and the influence of teaching. *British Journal of Educational Psychology*, *68*, 505–516.

Kikas, E. (2003). Constructing knowledge beyond senses: Worlds too big and small to see. In A. Toomela (Ed.), Cultural guidance in the development of the human mind (pp. 211–227). London: Ablex.

Linn, M. C. (2008). Teaching for conceptual change: Distinguish or extinguish ideas. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 694–722). NY: Routledge.Maria, K. (1996). A case study of conceptual change in a young child. *The Elementary School Journal, 98,* 69–89.

Maria, K. (1996). A case study of conceptual change in a young child. *The Elementary School Journal, 98*, 69–89.

McCloskey, M. (1983). Intuitive physics. *Scientific American, 248,* 122–130.

Nobes, G., Martin, A., & Panagiotaki, G. (2005). The development of scientific understanding of the Earth. British Journal of Developmental Psychology, 23, 47–64.

Nobes, G., Moore, D., Martin, A., Clifford, B., Butterworth, G., Panagiotaki, G., et al (2003). Children's understanding of the Earth in a multicultural community. Developmental Science, 6, 74–87.

Nobes, G., & Panagiotaki, G. (2007). Adults' representations of the Earth: Implications for children's acquisition of scientific concepts. British Journal of Psychology, 98, 645–665.

Nobes, G., & Panagiotaki, G. (2009). Mental models or methodological artefacts: Adults' "naïve" responses to a test of children's conceptions of the Earth. British Journal of Psychology, 100, 347–363.

Ohlsson, S. (1996). Learning from performance errors. Psychological Review, 103, pp. 241–262.

Opfer, J. E., & Siegler, R. S. (2004). Revisiting preschoolers' living things concept: A microgenetic analysis of conceptual change in basic biology. Cognitive Psychology, 49, 301–332.

Panagiotaki, G., Nobes, G., & Banerjee, R. (2006). Is the world round or flat? Children's understanding of the Earth. European Journal of Developmental Psychology, 3, 124–141.

Panagiotaki, G., Nobes, G., & Potton, A. (2009). Mental models and other misconceptions in children's understanding of the Earth. Journal of Experimental Child Psychology, 104, 52–67.

Piaget, J. (2005). *The psychology of intelligence* (M. Piercy & D.E. Berlyne, Trans.). New York: Routledge. (Original work *La psychologie de I'intelligence* published in 1947, Paris: Armand Colin).

Samarapungavan, A., Vosniadou, S., & Brewer, W. (1996). Mental models of the Earth, sun, and moon: Indian children's cosmologies. Cognitive Development, 11, 491–521.

Schnotz, W., Vosniadou, S., & Carretero, M. (Eds.). (1999). New perspectives on conceptual change. Amsterdam: Pergamon.

Schoultz, J., Säljö, R., & Wyndhamn, J. (2001). Heavenly talk: Discourse, artefacts, and children's understanding of elementary astronomy. Human Development, 44, 103–118.

Siegal, M., Butterworth, G., & Newcombe, P. (2004). Culture and children's cosmology. *Developmental Science*, *7*, 308–324.

Siegal, M., & Surian, L. (2004). Conceptual development and conversational understanding. Trends in Cognitive Science, 8, 534–538.

Siegler, R., & Chen, Z. (2002). Development of rules and strategies: Balancing the old and new. *Journal of Experimental Child Psychology, 81,* 446–457.

Siegler, R., & Svetina, M. (2006). What leads children to adopt new strategies? A microgenetic / cross-sectional study of calss inclusion. *Child Development, 77,* 997–1015.

Smith, C., Maclin, D., Grosslight, L., & Davis, H. (1997). Teaching for understanding: A study of students' preinstruction. Theories of matter and comparison of the effectiveness of two approaches to teaching about matter and density. *Cognition and Instruction*, *15*, 317–393.

Spelke, E., & Kinzler, K. (2007). Core knowledge. Developmental Science, 10, 89–96.

Straatemeier, M., van der Maas, H. L. J., & Jansen, B. R. J. (2008). Children's knowledge of the Earth: A new methodological and statistical approach. *Journal of Experimental Child Psychology, 100,* 276–296.

Tulving, E., & Thomson, D.M., (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review, 80,* 352–373.

Uibu, K., Kikas, E., & Tropp, K. (2010). Teaching Practices, Their Dynamics, Associations with Self-Reported Knowledge and Students' Language Achievement. In A. Toomela (Ed.), *Systematic Person-Oriented Study of Child Development in Early Primary School* (pp. 47–71). Frankfurt am Main: Peter Lang Verlag.

Vamvakoussi, X. & Vosniadou, S. (2004). Understanding the structure of the set of rational numbers: a conceptual change approach. *Learning and Instruction, 14,* 453–467.

von Eye, A. (1990). Introduction to configural frequency analysis. In *The search for types and antitypes in cross-classifications*. Cambridge, UK: Cambridge University Press.

von Eye, A. (2001). *Configural frequency analysis, Version 2000. A Program for 32 Bit windows operating system. Methods of psychological research online*, 6(2). Retrieved August 10, 2006, from http://www.mpr-online.de.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Learning and Instruction, 4*, 45–69.

Vosniadou, S. (1996). Learning environments for representational growth and cognitive flexibility. In S. Vosniadou, E. De corte, R. Glaser & H. Mandl (Eds.), *International Perspectives on the Design of Technology-Supported Learning Environments* (pp.13–23). Mahwah, New Jersey: Erlbaum.

Vosniadou, S. (2002). On the nature of na¨ıve physics. In M. Limon & L. Mason (Eds.), *Reconsidering conceptual change: Issues in theory and practice* (pp. 61–76). Dordrecht, The Netherlands: Kluwer.
Vosniadou, S., & Brewer,W. F. (1992). Mental models of the Earth: A study of conceptual change in childhood. *Cognitive Psychology*, *24*, 535–585.
Vosniadou, S., Ioannides, C., Dimitrakopoulou, A., & Papademetriou, E. (2001). Designing learning environments to promote conceptual change in science. *Learning and Instruction*, *11*, 381–419.
Vosniadou, S., Skopeliti, I., & Ikospentaki, K. (2004). Modes of knowing and ways of reasoning in elementary astronomy. *Cognitive Development*, *19*, 203–222.
Vosniadou, S., Skopeliti, I., & Ikospentaki, K. (2005). Reconsidering the role of artifacts in reasoning: Children's understanding of the globe as a model of the Earth. *Learning and Instruction*, *15*, 333–351.
Vygotsky, L. (1997). Thought and language (A. Kozulin, Ed.). Cambridge, MA: MIT Press. (Original work published in 1934).
White, R. T., & Gunstone, F. F. (2008). The conceptual change approach and the teaching of science. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 619–628). New York: Routledge.
Wiser, M., & Smith, C. L. (2008). Learning and teaching about matter in Grades K–8: When should the atomic–molecular theory be introduced? In S. Vosniadou (Ed.), International handbook of research on conceptual change (pp. 205–239). New York: Routledge.

# SUMMARY IN ESTONIAN

## LASTE TEADMISED MAAST JA GRAVITATSIOONIST NING NENDE TEADMISTE MUUTUMINE ARENGU JA ÕPPIMISE KÄIGUS

Inimese teadmiste hulk muutub pidevalt nii igapäevase tegutsemise ja ümbritseva jälgimise käigus saadud isikliku kogemuse kui ka teistelt kuuldud ja kirjalikest tekstidest saadud verbaalse informatsiooni mõjul. Sealjuures on oluline nii isiklikule kogemusele tuginev teadmiste konstrueerimine kui ka juhendamise tulemusena ühiskonnas juba eksisteerivatest teadmistest teadlikuks saamine. Samas on ilmnenud, et mitte sugugi alati ei mõista ega kasuta inimesed kuuldut ja kogetut teaduslikus mõttes korrektselt. Osa uurijaid on väitnud, et inimestel on kooskõlalised väärarusaamad maailmast, osa autoreid aga usub, et enne teaduslikult tõestatud leidudega kattuva arusaama kujunemist on erinevad infokillud üksteisega vaid väga nõrgalt seotud.

Antud doktoritöös selgitati astronoomia-alaste teadmiste näitel seda, kuidas omandatakse ja väljendatakse uusi teadmisi ning kuidas täpsustada väliste tegurite (näiteks küsitlusmeetodid ja analüüsimeetodid) rolli teadmiste hindamises. Selleks viidi lasteaias ja eelkoolis läbi õpetavad eksperimendid, kus osales kokku 94 viie- kuni seitsmeaastast last (**Artiklid I** ja **II**) ning testiti arenguliste muutuste uurimiseks nelja aasta jooksul aastaste vahedega 143 lasteaialast, kes esimese testimise hetkel olid kahe- kuni kolmeaastased ning 159 kooliõpilast, keda esimest korda uuriti esimeses klassis (**Artiklid III** ja **IV**). Kõikide laste astronoomia-alaseid teadmisi uuriti lahtiste küsimuste ja joonistusülesannetega ning nende tulemusi analüüsiti nii grupi kui ka indiviidi tasemel. Doktoritöö põhitulemusi kajastati neljas artiklis.

Uurimaks õpetamise mõju teadmiste kujunemisele võrreldi verbaalse ja mudeleid kasutava õpetuse mõju (**Artikkel I)** ning vaadati mudelipõhise õpetuse efektiivsust erineva eelteadmiste tasemega laste teadmiste parandamisel (**Artikkel II**).

Selgus (**Artikkel I**), et erinevalt ootusest, mille kohaselt mudelitele tuginev õpetus peaks andma oluliselt paremaid tulemusi, kasvab laste poolt antud õigete vastuste hulk nii puhtalt verbaalse kui ka mudeleid ja näitlikustamist kasutava õpetamise tulemusena. Vaid mõne üksiku teema puhul (näiteks antud uurimuses gravitatsiooni teema) võib mudelite kasutamist pidada kasulikumaks. Samuti ilmnes (**Artikkel II**), et sõltumatult õppijate vanusest tõstab isegi mõne üksiku fakti eelnev tundmine oluliselt õpetusest saadavat kasu. Tulemused (**Artiklid I, II** ja **IV**) viitasid ka sellele, et õpetamises kasutatavate võtete ja vahendite valikult tuleks olla väga hoolikas, sest ebapiisavad seletused ning mudelid, millel on väga silmapaistvaid, kuid õppimise seisukohast täiesti ebaolulisi tunnuseid, võivad hoopiski soodustada väärarusaamade kujunemist.

Kuna üheks oluliseks vaidlusküsimuseks on olnud mitte-teaduslike teadmiste koosõlalisus ning uurimismeetodi roll teadmiste väljendamises, uuriti **Artiklites II, III** ja **IV** laste vastuseid ning nendes aja jooksul toimuvaid muutusi ja analüüsiti, kas mingil hetkel viitavad avatud küsimustele antud vastused kooskõlaliste mitte-teaduslike arusaamade olemasolule. Tulemused näitasid, et teadmiste kujunemises näib esinevat perioode, mil suureneb just selliste ebaõigete vastuste hulk, kus isiklikule kogemusele tuginevat teadmist on kombineeritud õpitud faktidega. Ennekõike seostub selliste vastuste kasv just teema sihipärase õppimisega (**Artiklid II** ja **IV**). Samas selgus indiviidikeskseid meetodeid kasutades (**Artiklid II, III** ja **IV**), et kooskõlaliste teooriat meenutavate vääruskumuste esinemissagedus on väga madal ning konfiguraalse sagedusanalüüsi tulemused viitasid, et tõenäoliselt on suurem osa varasemates uurimustes alternatiivsete teooriate eksisteerimise tõestuseks peetud vastuste kombinatsioonidest pigem juhusliku kokkusattumuse tulemus. Enamikul juhtudel on seega tegemist just eraldiseisvate teadmisekildudega, mida polegi üritatud ülejäänud faktiteadmiste või kogemustega seostada.

**Artiklid III** ja **IV** näitasid veel seda, et aja jooksul laste vastustes toimuvad muutused sarnanevad varem leitud muutustega probleemilahenduses – alguses keskenduvad lapsed vastates peamiselt vahetult tajutavate tunnuste kirjeldamisele, faktiteadmiste lisandudes tekib vajadus kooskõlastada isiklikule kogemusele tuginev info õpituga ning selle käigus võivad ajutiselt tekkida sünteetilised teadmiste ühikud. Vahel harva võivad lapse katsed teadmistes kooskõla saavutada viia sünteetilise teooria (näiteks uskumus, et Maa on seest tühi kera) kujunemisele. Enamasti on aga laste teadmised mõnda aega üsna fragmentaarsed ja viimaks kujunevad neist teadusliku teadmisega kooskõlas olevad arusaamad.

Kokkuvõtteks näitas doktoritöö, et muutus astronoomia-alaste teadmiste väljendamises sarnaneb teistes valdkondades (näiteks matemaatika- ja füüsikaülesannete lahendamine) toimuvate üleminekutega. Teadmiste kujunemise algfaasis tuginetakse ülesannete lahendamisel pigem isiklikule kogemusele ja alles hiljem hakatakse seda õpituga seostama. Teaduslike teooriate tulemuslikuks õpetamiseks ongi oluline *i)* arvestada õppijate olemasolevate teadmiste tasemega, *ii)* anda neile vajadusel algteadmisi ja põhifakte ning *iii)* pöörata tähelepanu sellele, et kasutatavad vahendid ja meetodid ise ei soodustaks väärarusaamade kujunemist.

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| 2001–2003 | Master's studies, Department of Psychology, University of Tartu |
| 1997–2001 | Bachelor's Studies, Department of Psychology, University of Tartu |

### Professional employment

| | |
|---|---|
| 2010– | School-psychologist, Viluste Primary School |
| 2008– | Lecturer of cognitive and school-psychology, Institute of Psychology, University of Tartu, |
| 2004–2008 | Lecturer of school psychology, Department of Psychology, University of Tartu, |
| 2002–2004 | School-psychologist and career-counsellor, Tartu Vocational Education Centre; |

### Research activity

Main research areas: Cognitive development; acquisition of concepts; children's knowledge of astronomy; learning and instruction.

### Membership in professional organizations

Estonian School Psychologists Association
Estonian Psychologist Association

27

# ELULOOKIRJELDUS

## Triin Hannust


| | |
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| Kodakondsus | Eesti |
| Sünniaeg | 28. juuli, 1979 |
| Aadress | Psühholoogia instituut, Tiigi 78, Tartu 50410, Eesti |
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### Haridus

| | |
|---|---|
| 2003–2010 | Doktoriõpe, psühholoogia instituut, Tartu Ülikool |
| 2001–2003 | Magistriõpe, Psühholoogia osakond, Tartu Ülikool |
| 1997–2001 | Bakalaureuseõpe, psühholoogia osakond, Tartu Ülikool |

### Teenistuskäik

| | |
|---|---|
| 2010– | koolipsühholoog, Viluste Põhikool |
| 2008– | kognitiiv- ja koolipsühholoogia lektor, Tartu Ülikool |
| 2004–2008 | koolipsühholoogia lektor, Tartu Ülikool |
| 2002–2004 | koolipsühholoog ja karjäärinõustaja, Tartu Kutsehariduskeskus |

### Teadustegevus

Peamised uurimisvaldkonnad: kognitiivne areng; mõistete omandamine; laste astronoomia-alased teadmised; õppimine ja õpetamine.

### Kuulumine erialastesse organisatsioonidesse

Eesti Koolipsühholoogide Ühing
Eesti Psühholoogide Liit

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