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CONTENTS

LIST OF ORIGINAL PUBLICATIONS

This dissertation is based on the following original publications which will be referred to in the text by their respective Roman numerals.

I **Kikas, E.** The development of word definitions in children. *Journal of Russian and Eastern European Psychology*, 1993, 31, 40–54.

II Wertsch, J. V., Hagstrom, F., & **Kikas, E.** Voices of thinking and speaking. In: L. Martin, K. Nelson, & E. Tobach (eds.) *Sociocultural psychology. Theory and practice of doing and knowing* (pp. 276–290), 1995. New York: Cambridge University Press.

III **Kikas, E.** The impact of teaching on students' definitions and explanations. (submitted)

IV **Kikas, E.** The impact of teaching on students' explanations of astronomical phenomena. *Language and Communication* (in press)

V **Kikas, E.** Students' understanding of astronomical phenomena. Development of verbal explanations and drawings. (submitted)

1. RESEARCH IN CONCEPTUAL DEVELOPMENT

1.1. Historical background

Jean Piaget was the first researcher who studied conceptual development by using the methodology that is acceptable today. His theory has had a tremendous impact on the development of the discipline. According to Piaget, the thinking of a child is different from the formal operational thinking of an adult. An individual constructs cognitive representations, which are dependent on his or her level of the development, by means of two complementary psychological mechanisms — assimilation and accommodation (1948, 1976). So, he stressed the internal activity of a child, formulating the idea in the expression: "To understand is to invent" (1973). Activity means internal manipulation of objects, meanings come from actions that the child performs on these objects, rather than from the objects themselves (1970). He differentiated between spontaneous and non-spontaneous concepts but was interested mainly in the development of spontaneous concepts, which truly reflect the characteristics of the child's mind (1948). Non-spontaneous concepts reflect the mastering of cultural knowledge being taken by a child from adults in a ready-made form. Piaget argued that social life is necessary for an individual to overcome egocentrism, to internalize societal norms and rules, and to develop self-consciousness. Cooperation between peers, which is a source of criticism, leads to autonomy; discussions give rise to reflection and objective verification. He saw the role of an adult mainly as a collaborator rather than that of a master (1932).

Piaget argued against traditional individualistic teacher-centered education, which prepares children for examinations rather than for life (1932). His theory has had an impact on child-centered progressive education, and at present it is enjoying even greater popularity (see below). First, constructivism as an educational ideology is based on his idea about the importance of child's own experimentation (1932, 1970, 1973). Second, group work as a widespread teaching method makes use of Piaget's ideas about the importance of collaboration between peers (1932).

Lev Vygotsky stressed more than Piaget the importance of society and cultural norms for children's conceptual development (1935). Children are acculturated into the society just through collaborating with more experienced persons, adults or peers. Different cultural tools or mediational means, for example, language, models, maps, and schemes that children have to master play a vital role in their mental development. The knowledge mediated by such signs as words, writing systems, schemata, diagrams, and maps is especially important because of its leading role in the development of higher psychological functions (1982a; 1994a).

More than Piaget, Vygotsky dealt with the impact of formal school education on children's development. In school, children have to master written language and scientific knowledge, solve problems different from everyday ones, and reflect on their thinking. This is why Vygotsky distinguished between scientific and everyday concepts (1982b, 1994b). Everyday concepts are mastered by being in direct contact with their references, or observing the corresponding phenomena, whereas scientific concepts are learned in school by verbal explanations. **Paper I** gives an overview of the characteristic features, differences in formation and development, strengths and weaknesses of scientific and everyday concepts. These problems are also discussed in **Paper III** and **Paper V**. The characteristics of child's thinking (e.g., pre-operational thinking level according to Piaget) follow from the fact that everyday concepts do not form a system, therefore the relationship between concepts reflects the relations between objects. Differently from Piaget, Vygotsky argued that scientific or non-spontaneous concepts are not acquired in a ready-made form, but their development is a time-consuming and complicated thinking process. When a child first hears a new word (e.g., in the form of a definition), its development is starting and not ending. Scientific concepts belong to a special system and are co-constructed by a student together with a teacher. This systematicity and co-operation helps a child to start to reflect on his or her own thinking and overcome the peculiarities of child's thinking.

Vygotsky, like Piaget, argued against traditional teacher-centered education. He warned against verbalisms in teaching, which may lead to a situation where children do not acquire concepts but words, relying mainly on their memory and not on thinking, therefore not being able to use their knowledge. He also emphasized the need for students to learn from their own activities. Students' role in school should not be reduced to the passive receptacle of knowledge. He wrote that children's thinking emerges in the context of dispute (1983), i.e., from cooperation and group work in school.

But more than the role of peers he stressed the role of teachers who intermediate society's scientific knowledge to students. He considered the asymmetric relationship in the cooperation between a developing child and his social environment to be the normative case, and saw a danger for the development if children cannot collaborate with adults and/or more experienced peers. These conclusions derive from the general genetic law of cultural development: "The higher psychological functions emerge first in the collective behavior of the child, in the form of cooperation with others, and only subsequently become internalized as the child's internal functions" (Vygotsky, 1983, p. 197). What a child and a teacher do together at first (e.g., talk about the ways of solving a problem), a child will do alone afterwards as the process will have been internalized by a child.

The concept of the zone of proximal development (ZPD) may be used to explicate the process of learning and development. ZPD is "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (1978, p. 86). Potential development becomes actual development through internalization. What a child can do in cooperation today, he can do alone tomorrow. An essential aspect of this interaction on ZPD is that less capable participants can participate in forms of interaction that are beyond their competence when acting alone. Ideal teaching should occur in ZPD and lead the development of a student.

1.2. Contemporary approaches

1.2.1. Heterogeneity of thinking

Traditional developmental theories have been criticized mainly on two grounds (e.g., Fodor, 1972):

1. The wrong view of adult concepts, consequently, children would be developing to a fictional final state. It is a "classical view" in which meanings of concepts can be described by lists of necessary and sufficient features (Smith & Medin, 1981). This view has been challenged on both empirical and theoretical grounds (e.g., Rosch & Mervis, 1975; Smith & Medin, 1981). Still, this view holds true for several subclasses of concepts including those used in scientific disciplines where exact usage of concepts is necessary (e.g., Tulviste, 1991).

2. If the shift in development is qualitative, children and adults have different kinds of concepts. Accordingly, they would be expected to misunderstand each other. For some reason, however, this total misunderstanding does not occur.

The cognitive revolution and the advent of sociocultural approaches has been accompanied by an emphasis on heterogeneity of thinking, which makes it possible to overcome the difficulties of traditional theories. The concept of heterogeneity is interpreted differently by different researchers.

Peeter Tulviste (1991) argues that each person possesses different types of thinking and relates the heterogeneity of thinking types to the heterogeneity of activities. Scientific thinking, characterized by logical argumentation and well-defined conceptual systems arises in school and is used for solving school (and afterwards, scientific) problems. As adults participate in other forms of activities besides scientific ones, the "older" types of thinking that correspond to them are preserved and continue to function. So, scientific thinking does not replace other types of thinking but arises beside them. An adult person uses different types of thinking to solve different types of problems. Children possess fewer types of thinking than adults, but mutual understanding is possible as some types of thinking coincide. Thinking develops as children participate in new culturally accepted activities.

James Wertsch (1991) elaborates the Vygotskian idea of cultural tools (such "mediational means" as language) as important determinants of development. He stresses that language functions differently in different sociocultural settings and makes use of Bakhtin's concepts of social languages and speech genres (Bahtin, 1987). Socialization involves mastering the rules for using particular speech genres in particular settings. A specific speech genre — the language of "official science" (or speech genre of formal instruction) — occupies a privileged position in school. But the development of a new speech genre (e.g., formal instruction) does not result in the disappearance of others. The theoretical problems of heterogeneity of thinking and speaking are discussed in **Paper II.**

Similar ideas of privileging are also expressed by the "literate register" (Watson, 1985; Snow, 1990) or "talking science" (Lemke, 1990; Howe, Tolmie & Rodgers, 1992). However, some authors write mainly about *talking* in a new genre, not so much about thinking or understanding. For example, Lemke writes: "Classroom language is not just a list of technical terms, or even just a recital of definitions. It is the use of those terms in relation to one another, across a wide variety of contexts. *Students have to learn how to combine the meanings of different terms according to the accepted ways of talking science.*" (1990, p. 12, my italics). While according to Tulviste (1991), students acquire a new type of thinking to be able to solve new types of problems, the question of why the genre of official science is privileged in school remains unanswered in Lemke's work. Moreover, I would argue that combining the meanings of terms according to the accepted ways of talking is not the same as understanding scientific discourse and thinking scientifically. Students learn to combine meanings and use scientific explanations very easily but it is not the same as thinking scientifically and/or understanding the phenomena in the way scientists do (cf. below parrotlike repetition; Vygotsky, 1994c). The study described in **Paper V** shows it quite well.

Empirical studies have documented the differences in thinking in different societies, sociocultural settings and during solving different problems (e.g., Rogoff & Lave, 1984; Cole, 1985; Tharp & Gallimore, 1988; Rogoff, 1990). In addition, it has been shown that lay adults use everyday thinking while arguing about physical, biological, psychological etc. phenomena, even if they have been taught scientific explanations in school. They possess naive theories (everyday science, intuitive science) which differ from contemporary scientific theories even after formal teaching in school (McCloskey, 1983; Driver, 1990; Lewis, & Linn, 1994; Byrnes & Torney-Purta, 1995; Wegener & Petty, 1995). These results are in accordance with Tulviste's approach, which tells that if there is no need in one's later life to solve scientific problems, the ability of scientific thinking may decline (also Luria, 1976; Rabinovitz & Mandler, 1983).

1.2.2. Young children's naive theories

Recent research has also shown, however, that young children have significant implicit understanding of the principles that are important for understanding in such domains as mathematics and science (Carey, 1985; Wellman & Estes, 1986; Keil, 1989; Resnick, 1989). Also, pre-school children have quite an extensive knowledge in a variety of domains that is not as fragmented as it was thought before but compromised into theories (called naive or intuitive theories, mental models) (Carey, 1985; Driver, Guesne & Tiberghien, 1985; Neisser, 1987; Ruble, Newman, Rholes & Altshuler, 1988; Keil, 1989; Inagaki, 1990; Chi & Slotta, 1993; Hatano & Inagaki, 1994; Vosniadou & Brewer, 1994). It has been argued that these principles and theories are derived from children's everyday sensory experiences and they enable children to interpret the phenomena, make sense of the world and solve problems (Carey, 1985; Greeno, 1989; Vosniadou & Brewer, 1994; Driver, Squires, Rushworth & Wood-Robinson, 1995). Children's personal knowledge varies to a degree that is consistent with scientific knowledge (Glynn & Duit, 1995).

These results provide evidence that children should not be considered as mere receptacles for receiving knowledge when they learn in school. Naive models influence the acquisition of new knowledge. Instead of acquiring new concepts, students should elaborate, modify and reorganize their initial concepts. In fact, it has appeared that children's models are very difficult to change by teaching, especially if they differ essentially from scientific explanations, and, therefore, radical restructuring of knowledge is inevitable (Driver, Guesne & Tiberghien, 1985; Neisser, 1987; Vosniadou, 1992; Chi, Slotta & Leeuw, 1994; Vosniadou & Brewer, 1994). Students learn from school the knowledge that does not contradict their everyday models. They also form synthetic models (sometimes called misconceptions), which are compromises between everyday beliefs and school knowledge (Vosniadou, 1992). Sometimes they acquire scientific concepts verbally (mere verbalisms according to Vygotsky), and fail to integrate them later with everyday models. An overview of research on children's astronomical concepts and their development is given in **Paper III, Paper IV** and **Paper V**.

So far, cognitive scientists have paid little attention to the ways new knowledge is taught in school, and to why knowledge restructuring had not taken place during learning. They have not studied the discourse of textbooks and lessons, but these problems have been studied by educational psychologists.

2. RESEARCH IN EDUCATIONAL PSYCHOLOGY

2.1. Traditional education

Behaviorism was the paradigm behind traditional educational psychology beginning with Edward L. Thorndike until at least the 1970s. Although the cognitive revolution had an impact on educational psychology, changing the point of interest towards the cognitive and motivational development of an individual, the differences between in- and out-of-school education etc., behavioral theories of learning are dominant even in several new textbooks, including the one translated into Estonian (Lindgren & Suter, 1994). In general, schools are quite resistant to change, behavioral ideology being still quite persistent there.

Students are only passive recipients not active knowledge builders in the traditional classrooms, where the instructional mode of lecture, question and answer is widely used. Learning is identified with "just listening". The typical structure of classroom discourse (the interactional sequences mostly used in classrooms) is the following: teacher's initiation — student's reply — teacher's evaluation (IRE sequence) (Mehan, 1979). Teachers deliver facts and explanations, and the students' task is to memorize them in order to know the answer to the evaluative questions (Glynn & Duit, 1995; Glynn, Yeany & Britton, 1991). These are the methods against which Vygotsky warned: "Direct teaching of concepts is impossible and fruitless. A teacher who tries to do this usually accomplishes nothing but empty verbalism, a parrotlike repetition of words by a child, simulating a knowledge of the corresponding concepts but actually covering up a vacuum" (1994c, p. 150).

It has been shown that traditional school books and teaching give such new information (facts, definitions, explanations) that does not take into account students' previous (naive) conceptions (Michaels & Bruce, 1989; Renner, Abraham & Grzybowsky, 1990; Pizzini, Shepardson & Abell, 1992; Driscoll, Moallem, Dick, & Kirby, 1994: McNeal, 1995; Stinner, 1995). This new knowledge could remain quite far-fetched and abstract and is not integrated with the child's everyday knowledge.

These practices have been and still are characteristic of Estonian mainstream education. One compulsory curriculum for all schools, big class sizes, no time for individual work, teaching directed toward an "average child", based mainly on memorization, teachers unprepared for working with children's special needs, their poor knowledge of alternative teaching methods and psychology — these are the realities of our school even today (e.g., Leuhin, 1996; Sokk, 1996). Our school leaders are proud of our students' good (factual) knowledge, students are considered to be "blank sheets of paper" who should be filled with school knowledge. Unfortunately, such perceptions are very far from the truth. This type of lessons are described in **Paper III**.

2.2. Alternative education

Alternative ideology in education, described as progressive (as opposed to traditional) and child-centered (as opposed to teacher-centered) (Withall, 1987) arose already in the beginning of the century (e.g., Dewey, 1916, 1938; Montessori, 1928, 1973). Since the 1960s and 1970s a number of democratic societies have made systematic attempts to introduce child-centered methods into schools. Discovery learning (Bruner, 1960, 1966), meaningful verbal learning (Ausubel, 1963), conceptual change learning (Posner, Strike, Hewson & Gertzog, 1982) — these represent only a few of the influential alternative teaching methods. These methods stress the need to make use of children's natural curiosity and to reinforce their interest in learning.

A constructivist or constructive view of learning, proceeding from Immanuel Kant and being based, besides others, on Piaget's ideas, has been popular for several decades (Hendry, 1996). Learning is considered here a process of constructing and reconstructing personal theories and models. When students learn science meaningfully, they activate their existing knowledge, relate it to their educational experiences, and construct new knowledge in the form of conceptual models, which consist of related concepts, not lists of unrelated facts (Glynn & Duit, 1995; Glynn, Yeany & Britton, 1991).

In reality, if the child-initiative-activities are overemphasized, it may result in quite alienating activities, where the learning potential is unsatisfactorily used (Bergqvist & Säljö, 1994). It is not enough to permit a child to discover the reality. Scientific explanations are theory-based and cannot be derived from observations only (Kuhn, 1962; Popper, 1963; Tulviste, 1991; Carey & Smith, 1993; Tiberghien, 1994; Albanese, Danhoni Neves & Vicentini, in press). Actually, it is a widespread naive assumption that the physical world is immediately given, and that it can be understood essentially without mediation by means of cultural tools such as language and models. The assumption that students can generate their own questions and find answers to the questions that constitute modern science (cf. Gallas, 1995) is too simplistic; it is not enough to build lessons only on children's questions, using inductive types of learning. For formulating appropriate questions (which is as difficult as formulating good answers) which enable to get an insight into the discipline, the following theory is obligatory (Bergqvist & Säljö, 1994; Tiberghien, 1994). So, proceeding from students' interests and activating them (e.g. through experimentation, generating their own questions and looking for answers, participating in group work) is necessary but not enough (cf. Kikas & Hagstrom, 1993).

The teacher's role in student-centered teaching/learning should be twofold. First, only she or he is able to provide knowledge not only of concrete phenomena (seen by experimentation) but of a wider theoretical perspective, assisting the development of students' scientific thinking. So, it is not only students' experiments and questions that are important, but teachers' generative questions and interpretations are important as well (e.g., Champagne, Klopfer & Gunstone, 1982). Second, a teacher can facilitate the conceptual development and change in each student if the potential of ZPD is made use of (education is ahead of development). The actualization of knowledge on ZPD takes place with the help of teachers in school (e.g., Tharp & Gallimore, 1988; Moll, 1990).

Earlier research in conceptual development and educational psychology has shown that:

1) children have integrated knowledge of natural phenomena;
2) teaching changes it quite little;
3) the reasons why the change does not occur could be partly explained by traditional teaching methods.

According to the sociocultural approach, it is very important to study in detail such activity settings as school and mediational means such as language. But there are very few thorough empirical investigations, which study conceptual development and change and take into account students' earlier knowledge and the ways of teaching and learning. My empirical research deals with these problems.

3. CONCEPTUAL DEVELOPMENT AND IMPLICATIONS FOR EDUCATION: EMPIRICAL RESULTS

3.1. Methodology

The defining method is one of the oldest methods for studying conceptual development (e.g., Feifel & Lorge, 1950; Litowitz, 1977; Watson, 1985; Snow, 1990). The pluses and minuses of this method are discussed in **Paper I**. The method was used in studies described in **Paper I** and **Paper III**.

Unstructured interviews have been used both in the research on conceptual development and science teaching (Luria, 1976; Carey, 1985; Michaels & Bruce, 1989; Lewis & Linn, 1994; Bell, 1995; McNeal, 1995). In such interviews, questions are adjusted to a child's answers. Parallels could be drawn with Piaget's clinical interviews (Piaget, 1929). Such interviews are used in **Paper III.**

Vosniadou (Vosniadou, 1992; Vosniadou & Brewer, 1992; 1994) has differentiated between two types of questions: factual and generative. They stress that the latter are of greater use in conceptual development research. Generative questions are about phenomena that individuals cannot observe directly, and about which they are not likely to have received any direct instruction. These questions have the potential to reveal the kinds of mental models that individuals use generatively, as opposed to the kind of information they have memorized and used in familiar, school-related situations. The problem with the research described in **Paper IV** is just that it is based mainly on factual questions. Factual questions are asked also in school to assess children's knowledge.

Illustrations, besides verbal descriptions, are another way to represent knowledge. Children's drawings have also been used to study their concepts (e.g., Vosniadou & Brewer, 1992; 1994; Arnold, Sarge & Worrall, 1995; Baxter, 1995). Illustrations are used in the study described in **Paper V.**

Observation and discourse analysis of textbooks and lessons have been used in educational studies as well (e.g., Mehan, 1979; Heath, 1987; Michaels & Bruce, 1989). All my empirical studies conducted an initial analysis of the ways how terms and topics were treated in textbooks. Lessons' discourse was analyzed in the study described in **Paper III.** The first half of this investigation was a part of a cross-cultural study carried out in collaboration with Sarah Michaels of the Literacy Institute (Cambridge, MA, USA). An overview of the methodology is given in the work by Michaels and Bruce (1989). This study was longitudinal, others were cross-sectional.

3.2. Main results

All my empirical research was carried out in ordinary Estonian schools. The last three studies deal with the problems of conceptual development and change in the field of astronomy. The aims and the main results of the studies are the following.

1. The aim of the first investigation (**Paper I**) was to study the differences between definitions of scientific and everyday concepts. The results did not confirm the Vygotskian hypothesis concerning the developmental advantage of conscious awareness of scientific concepts over everyday ones. These results showed that the pre-school knowledge plays an important part in later development in school (cf. Glynn & Duit, 1995).

2. The analysis of elementary and middle school science textbooks showed that emphasis is on the definitions of terms and long descriptions of phenomena. The explanations in books fail to take into account children's naive knowledge, nor do they stress the critical knowledge that is necessary for understanding scientific explanations. The same problems with school text books have been stressed in the literature as well (e.g., Michaels & Bruce, 1989; Stinner, 1995).

The classroom study (**Paper III**) showed that the teaching was based heavily on the textbook, the teacher retold the textbook several times. There was no discussion of students' everyday knowledge. The teaching relied mainly on memory and not on thinking (cf. Vygotsky 1994c). The teacher used only factual questions in assessing students' understanding. The answers to these questions were provided in the book and had been stressed by the teacher earlier (cf. Vosniadou, 1994). Students were passive receivers of knowledge. Several researchers have stressed that it is impossible to acquire knowledge in this way (Piaget, 1973; Vygotsky, 1983; Glynn & Duit, 1995). Students had no other possibility to use the knowledge that was learned in classroom than to answer to the teacher's questions (cf. Tulviste, 1991; Howe, Tolmie & Rodgers, 1992; Bergqvist & Säljö, 1994).

3. All the studies indicated a strong influence of teaching on students' verbal explanations shortly after teaching in school ("exact" explanations of 5th graders). In older grades, new themes derived from the lately studied topics emerged in the answers (e.g., climate zones that were studied in the 7th grade). These results differ from the earlier research done in the U.S. in that students did not know scientific explanations even shortly after learning them (e.g., Sadler, 1987; Michaels & Bruce, 1989).

However, students soon forgot the scientific explanations and facts and returned to their everyday knowledge — 7th and 9th grade students gave fewer "exact" and more "aggregate" explanations than 5th graders (both longitudinal and cross-sectional data). It seems that students only memorized the school knowledge but did not understand it and, therefore, did not integrate it with everyday knowledge. So, the verbal acquisition of knowledge was quite illusory.

4. On the other hand, the impact of teaching on students' drawings was not considerable. Although textbooks provide schemes to help students understand the topic, teachers do not require their memorization. It seems that one part of students acquired the verbal facts and illustrations separately at first, memorizing mainly the verbal school knowledge (as is usually required by the teacher) but did not draw their illustrations on the basis of explanations. Drawings, rather than explanations, enable us to determine how students have understood the phenomena.

5. The results show that the teaching which stresses memorization can give outwardly good results shortly after learning the topic in school. Such teaching, however, is not effective in the longer perspective. Students can incorporate new school knowledge into their answers very easily. But as the teaching does not encourage the integration of everyday and school knowledge, students tend to forget the explanations and fall back to their everyday explanations.

6. The results raised the question of assessing students' understanding of knowledge. In school teachers assess the acquisition and understanding of students' knowledge mainly with such questions to which the answers are given in the textbook, i.e., with factual questions (cf. Vosniadou, 1994). The studies showed that the correct answers of 5^{th} graders did not mean that they had understood the phenomena. "Good" answers were, in fact, repetitions of the wording that was to be found in books, and students were able to provide them without fully understanding their meaning. They are mere verbalisms, parrot-like repetitions, against which Vygotsky warned (Vygotsky, 1994c). Asking students to illustrate their explanations is one possible way to gain a deeper insight into students' understanding.

I am fully aware that the results of my study do not enable me to draw far-reaching conclusions about the impact of school education on students' conceptual development. So far, I have studied the development in the field of astronomy; classroom discourse was studied in one school only. It would be necessary to study the conceptual development and change of other concepts as well. In addition, at present it is possible to conduct a comparative study of Estonian students who attend ordinary mainstream and alternative schools.

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KOOLILASTE MÕISTETE ARENG: KOOLIHARIDUSE MÕJU

Kokkuvõte

Dissertatsioonis käsitletakse laste mõistete arengu teoreetilisi ja praktilisi küsimusi. Antakse ülevaade probleemi uurimise ajaloost, alates J. Piaget' ja L. Võgotski töödest, ja tänapäevastest rõhuasetustest. Tõdetakse, et varasemad tööd kognitiivses ja hariduspsühholoogias on näidanud, et 1) lastel on loodusnähtustest integreeritud ettekujutused; 2) kooliharidus muudab neid suhteliselt vähe ja 3) võib oletada, et põhjus, miks muutust mõistetes ei toimu, peitub vähemalt osaliselt traditsioonilises õpetamismetoodikas. Lähtun sotsiokultuurilisest käsitlusest, kus rõhutatakse, et on oluline uurida keskkonda, kus tegevus toimub, ning märgilisi vahendajaid, mille abil teadmisi edastatakse. Väga vähe on empiirilisi töid, kus uuritakse mõistete arengut ja muutumist, võttes arvesse nii laste eelteadmisi kui õpetamise viise. Minu empiirilised uurimused püüavad seda lünka täita.

Dissertatsioonis esitatud järeldused põhinevad järgmistel töödel.

I töö eesmärgiks oli kontrollida Võgotski hüpoteesi teaduslike mõistete teadvustamise eelisarengust võrreldes tavamõistetega tänapäeva Eesti ühiskonnas. Tulemused ei kinnitanud hüpoteesi, viidates sellele, et enne kooli omandatud teadmistel on hilisemale arengule suur tähtsus.

II töös käsitletakse mõtlemise ja keele heterogeensusega seotud teoreetilisi küsimusi. Rõhk on koolikeele eripära analüüsimisel.

Kolmes viimases töös uuritakse empiiriliselt koolilaste mõistete arengut ja koolihariduse mõju sellele arengule astronoomiliste mõistete näitel. Kõik uurimused on tehtud tavalistes eesti koolides.

III töö kirjeldab longituuduurimuse (20 last, 5. ja 9. klass) tulemusi. Uuriti kooliõpetuse mõju laste astronoomia-alastele definitsioonidele ja selgitustele. Töös analüüsiti õpikuid ja töövihikuid ning õpetamisviise. Lapsi intervjueeriti kaks korda: kaks kuud ja neli aastat pärast teema läbimist koolis. Tulemused näitasid, et kaks kuud pärast õppimist vastasid lapsed enam-vähem õpikusõnadega, kuid neli aastat hiljem esitasid enamasti tavaseletusi.

IV töö kirjeldab ristlõikelise uurimuse (252 õpilast, 3., 5., 7., 9. klass) tulemusi. Uuriti õpetuse mõju laste astronoomia-alastele selgitustele. Selgitused jagati kooli (nt, öö ja päev vahelduvad, sest maa pöörleb ümber oma telje) ja tavaselgitusteks (nt, öö ja päev vahelduvad, sest me peame puhkama). Tulemused kinnitasid varasema töö tulemusi. Näidati õpetamise tugevat mõju 5. klassi laste selgitustele. Kuid et lapsed õppisid selgitused vaid pähe, unustasid nad need varsti ja pöördusid vanemates klassides tagasi tavaseletuste juurde. Samas lisandusid õpilaste vastustesse uued mõisted ja teemad, mis pärinesid äsjaõpitavast materjalist (nt, kliimavööndid aastaaegade vaheldumise selgitamisel).

V töö kirjeldab sama ristlõikelise uurimuse tulemusi, kuid lisaks seletustele analüüsitakse ka illustratsioone. Nii seletused kui ka joonised jagati täpseteks, agregaat- ja kirjeldavateks vastusteks. Näidati õpetamise tugevat mõju selgitustele, kuid mitte joonistele. Osa 5. klassi õpilasi, kes andsid täpse selgituse, illustreerisid oma vastust agregaat-joonistega. See näitab, et nende head verbaalsed teadmised olid näilised. Hiljem pöörduvadki need lapsed tavaselgituste juurde tagasi.

Tehtud tööd näitavad, et mõistete arengu uurimisel on sotsiokultuurilise konteksti arvestamine väga oluline. Varasematest töödest on selgunud, et lastel on sügavalt omaksvõetud koolieelsed, nüüdisaegsetest seletustest erinevad tavaseletused, mis säilivad ka vaatamata kooliõpetusele. Seda, kuidas uusi teadmisi koolis tegelikult õpetatakse, on varasemates töödes vähe uuritud. Dissertatsiooni tööd võimaldavad analüüsida ja põhjendada, miks koolis õpetatavaid mõisteid ei omandatud.

Empiiriliste uurimuste rakenduslikust aspektist huvipakkuvad tulemused on järgmised.

1. Eesti kooliõpikutes on rõhk terminite õpetamisel. Raamatus kirjeldatav ei arvesta laste tavateadmistega. Õpetus klassis tugineb oluliselt õpikule. Õpetaja jutustab ümber raamatu teksti, õpilased on suhteliselt passiivsed vastuvõtjad, kes peavad vastama õpetaja küsimustele. Esitatavatele küsimustele on võimalik õpikust vastust leida. Paljud teadlased (Piaget, 1973; Võgotski, 1983; Glynn & Duit, 1995) rõhutavad, et niimoodi on teadmisi omandada võimatu.
2. Õpetamine muudab tugevalt laste verbaalseid selgitusi vahetult pärast teema läbimist. Lapsed liidavad õpitavat oma selgitustesse väga kergesti. Kuid nad unustavad koolis õpitu varsti, pöördudes tagasi oma tavaselgituste juurde. Samasugust mõju joonistele ei leitud. Tundub, et osa lapsi omandab joonised ja selgitused eraldi, õppides pähe vaid sõnad, seejuures mitte mõistes nende sisu. Mittemõistmine avaldub kummalistes joonistes.
3. Kooliõpetus, kus rõhk on päheõppimisel, võib anda väliselt häid tulemusi vahetult pärast õpetamist, kuid pole efektiivne kaugemas perspektiivis.
4. Tulemused tõstatasid ka küsimuse, kuidas hinnata mõistetest-nähtustest arusaamist. Faktilised küsimused (vrd Vosniadou, 1994) seda teha ei võimalda. "Head" vastused võivad olla lihtsalt õpiku teksti kordamine. Illustreerimine on üks võimalus sügavama arusaamise hindamiseks.

Loomulikult ei saa tehtud tööde põhjal teha koolihariduse mõju kohta suuri üldistusi, uuritud on siiski vaid ühte mõistete valdkonda, tunnis toimuvat on kirjeldatud vaid ühes klassis. Tulevikus oleks vaja uurida ka teiste mõistete arengut ja koolihariduse mõju. Lisaks saab tänapäeva Eestis teha tava- ja alternatiivkoolide õpilaste võrdlevaid uuringuid.

PUBLICATIONS

I

Kikas, E. The development of word definitions in children. *Journal of Russian and Eastern European Psychology*, 1993, 31, 40–54.

EVE KIKAS

The Development of Word Definitions in Children

Many studies have dealt with the development of word definition in children. An account of the earlier studies is given by Feifel & Lorge [1]; the later ones, by a number of investigators [2–16]. As a rule, researchers have studied American or European middle- and upper-class children who were age four and older. They have usually asked children to define words with which they were all familiar.

In all the studies, researchers have found qualitative differences between the types of definition used by younger and older children; these have been attributed to differences in their conceptual thinking. Younger children define words nonabstractly (using mainly functional and descriptive definitions, repetition, pointing, and examples) whereas children age nine and older more frequently define abstractly. Results concerning the relative weights of descriptive and functional definitions are equivocal. In some studies young children give more descriptive definitions [2]; in others, more functional ones [4].

Certain factors must be taken into account when interpreting the results of previous studies. First, problems exist with the classification of definitions. In classic theories, adults' thinking has been treated as universal and, in modern societies, abstract. Knowledge is said to consist of static and well-packed information in which definitions correspond uniquely to the objective world. These assumptions proceed from an Aristotelian understanding of adults' definitions, which rests on specific defining attributes of properties. This view began to change with Rosch's work [17], which demonstrated that even adults' "world views" and arrangements of concepts in memory are not static, but

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more or less dynamic. Numerous other studies have reinforced this point [18,19]. Therefore, simple classifications (abstract/nonabstract or abstract/functional/descriptive definitions) seem to be insufficient even to characterize adults' conceptual thinking. It is especially difficult to treat definitions given by children and by members of traditional societies in such a concrete way because of their wide variety [12,20].

Secondly, the task of defining is quite artificial. Correct use of many concepts does not require their preliminary conscious definition [21], nor are definitions demanded in everyday life [12]. Defining is required for concepts the use of which demands accuracy, or when a correct classification has high value [11,22]. Defining is important in contemporary science, but not in many other spheres of activity [23]. The method is adequate specifically for studying the development of formal types of (e.g., scientific) thinking [23].

Earlier studies have paid little attention to the question of why the type of definition changes with age. We assume that the growing role of abstract definitions should first of all show the development of scientific thinking in the child, which is shaped by formal education. To demonstrate this, we constructed tests on the basis of the data distilled from analyses of schoolbooks. We based our work on Vygotsky's theory of the cultural development of higher psychological functions [24–26]. Before proceeding, let us consider the main points of his theory (concerning the development of concepts) in current contexts.

Concept development: A Vygotskian approach and beyond

The concept as a unit of verbal thinking has an important role in Vygotsky's theory about higher psychological functions. Vygotsky sees the reasons for the development of these processes in general, as well as the reasons for the development of concepts in particular, as cultural. He distinguishes between scientific and everyday concepts [24,26] and associates the impact of science on the child's thinking processes (the development of scientific thinking) with the formation and development of new kinds of concepts, namely, scientific ones. It is important to stress that Vygotsky does not regard scientific concepts simply as those related to natural or exact sciences; rather, he identifies scientific concepts with those learned in school.

The characteristic features of scientific concepts are:

1. They belong to special conceptual systems.

2. The thinker is consciously aware of them, i.e., reflects on them.

3. They enter into "supraempirical," experience-external connections.

When studying the development of verbal thinking processes and, especially, the development of scientific thinking, it is essential to consider that, according to Vygotsky, scientific and everyday concepts develop in different ways. The main differences are:

1. *Differences in formation*: A child masters an everyday concept by being in direct contact with its denotatum (the object[s] to which the word for that concept refers); scientific concepts are learned verbally, by definition.

2. *Differences in development*: An everyday concept develops "upward" (from a concrete object to general abstractions) whereas a scientific concept develops "downward" (initially given in a concept's system, it later becomes more concrete).

3. *Different strengths and weaknesses*: Children can *use* everyday concepts better in everyday situations, without being conscious of their meaning, whereas they can *define* scientific concepts better, though they may be unable to use them in concrete situations.

According to Vygotsky, children first start to define abstractly those concepts that are taught in school by definitions, i.e., scientific concepts. The ability to define abstractly is only afterward extended to everyday concepts in which the objects referred to are well known to children, but which lack the inevitability of being defined. The developmental advantage of scientific concept awareness compared with everyday concept awareness has been confirmed by several experiments in communities into which formal schooling has been introduced [23,27].

Tulviste [23] showed that the Vygotskian classification of concepts into scientific and everyday ones requires revision in several aspects. He stressed the need to correlate the typology with concrete types of activity—the properties of scientific concepts, for example, with the peculiarities of science. At least two questions arise when equating scientific concepts with those studied in school in modern societies. First, not all concepts are studied by means of abstract definitions in school. Teaching, especially in elementary grades, builds on children's everyday knowledge. Second, modern societies are so "permeated" with academic discourse that children become acquainted with defining even before entering school [28,29]. Here the spheres of activity and knowledge at home and in school are not absolutely separated as they are in societies into which formal schooling is introduced from outside [30]. Several studies have shown that home socialization has a significant impact on children's later development in school [10,16,31].

Tulviste mentions that little is known about the factors in schooling that promote the development of scientific thinking (and scientific concepts) in children. He writes: "We know little how the peculiarities of science . . . manifest themselves in the information assimilated in school and in solving school problems" [23. P. 157]. Vygotsky stressed the importance of acquiring literacy (see also [32]) and acquiring scientific knowledge. He introduced the notion of the zone of proximal development (ZPD), which is defined as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or [in] collaboration with more capable peers" [25. P. 86]. It "permits us to delineate the child's immediate future and his dynamic developmental state, allowing not only for what already has been achieved developmentally but also for what is in the course of maturing" [25. P. 87] (see also [24,26]). Much research has been carried out on the ZPD (see, e.g., [33–36]. Mainly, these have been studies focusing on problem solving either in everyday life or in school. No attention has been paid to its connection with scientific and everyday concepts.

Vygotsky also used the notion of the ZPD to discuss the developmental advantage of scientific concepts compared with everyday ones, speaking of scientific concepts as belonging to the level of actual development and of everyday concepts as belonging to the level of potential development ([24] the phrase is not translated into English in Vygotsky's later work [26]). The actualization of knowledge in a ZPD (the development of everyday concepts) takes place with the help of teachers in school. Vygotsky did not describe specific ways in which this was accomplished during lessons.

The development of definitions of scientific and everyday concepts has not been studied comparatively in modern societies; hence, our experiments are aimed at such a comparison. The defining test was constructed on the basis of previous analyses of textbooks. It enabled us to include scientific concepts (according to Vygotsky's definition) in the test. In addition to studying schoolchildren by means of the defining test, we studied kindergarteners by means of a concept comprehension test (using the same words as in the defining test). This enabled us to take into account more concretely children's preschool knowledge of definitions .

Selection of concepts for the test

To determine the influence of formal education on word defining and to test the Vygotskian hypothesis of the developmental advantage of scientific concepts (compared with everyday ones), the tests were constructed on the basis of data acquired by analyzing schoolbooks.

In Estonian schools, each child has one textbook per subject and one or two workbooks to accompany each textbook. Teachers follow the books very precisely, so an analysis of the books provides a good idea about what is taught in a classroom. Generally, theoretical knowledge (definitions, descriptions, etc.) is given in the textbooks, and problems, in the workbooks. Children study from the same books while doing homework at home. Teachers question children to some extent on their knowledge (including asking for definitions) of each lesson. Written tests are given once or twice a semester.

We included mathematics and natural science concepts as representatives of scientific concepts in our study. These concepts present contrasts in several ways. For example, it is difficult (if not impossible) even for scientists to give exact definitions (to list necessary-and-sufficient features) of many natural phenomena, whereas such definitions are commonplace in mathematics. Accordingly, differences between the development of children's definitions of mathematics and natural science concepts can be presumed. Textbooks and workbooks on these subjects in the first through fifth grades were analyzed in terms of the following questions:

1. When does the defining of concepts begin in school?
2. What kind of definitions are produced?
3. What kind of knowledge system (either everyday or scientific) is taught?

We found differences in teaching definitions in the first through second and third through fifth grades. In the first two grades, the main emphasis in mathematics is on teaching addition and subtraction, although some abstract definitions are taught as well. In natural science classes, the emphasis is on external descriptions of phenomena and on bringing out their usefulness. The material in the second grade is not divided according to scientific knowledge systems, but into: "Garden," "Nature around us," and "Field and domestic animals." Abstract concepts are taught systematically in mathematics from the third grade on. In the third grade, natural science is taught also by scientific domain. Definitions are stressed from the third grade on.

Twenty-six words were used to elicit concepts in tests: orange, blueberry, apple, bicycle, airplane, bat, bee, winter, the sun, the earth, river, lake, eye, water, lawn, weed, air, square, melting, ice, liquid, day and night (one word in Estonian), minute, meter, weighing, and measuring. In the Vygotskian sense, the tests include everyday concepts not studied in school, e.g., *orange*; scientific concepts studied in school by definitions, e.g., *square*; and, so to speak, intermediate concepts, which are known from everyday life and also studied in school (usually in new, scientific connections, e.g., *the sun*). We were thus able to compare the development of definitions of scientific and everyday concepts. Our study with kindergarteners using the concept comprehension test enabled us to take into account children's preschool passive knowledge of definitions.

Experimental study 1: Concept comprehension test

Testing procedure

It has been shown that even little children can comprehend the members of abstract categories even though they do not categorize abstractly themselves [37,38].

We studied children's comprehension of concepts from abstract definitions. Rather than ask for the definition of a word, we gave the abstract definition and asked for the word in response. This test enabled us to study the concepts that children knew passively. In other words, the children did not need to be able to define the word, but only to recognize it by its definition.

Responses (definitions) for the 26 study words were taken from the Estonian Child Encyclopedia or from textbooks. Twenty-six 5- and 6-year-old children from a kindergarten in Tartu (the second largest town in Estonia, with a population of more than 100,000) participated in the study. An experimenter told the children that it was a guessing task. She read aloud definitions to each child separately. After each definition she asked from a child: "Do you know what it is?"

Results

On the basis of the test results, the concepts could be divided into four groups:

1. Well-known concepts (66%–100% correct answers): orange, blueberry, apple, bicycle, airplane, bat, bee, winter, the sun.
2. Moderately well-known concepts (33%–66% correct answers): water, eye, river, lake, the earth.
3. Little-known concepts (10%–33% correct answers): lawn, weed, air, square.
4. Unknown concepts (no correct answers): melting, ice, liquid, day and night, minute, meter, weighing, measuring.

The results of the concept comprehension test indicated that children enter school with passive knowledge of definitions of some concepts. As we assumed, there are also several concepts that children learn only later in school.

Experimental study 2: Word definition test

Testing procedure

In this study we used the definition method in a classic way, i.e., the children responded to the question "What is x?" Data were collected at a representative school in Tartu. Children enter school at approximately 7 years of age and may study there for 11 years. We studied schoolchildren in grades one through five during lessons. An experimenter gave the children lists with words to be defined in writing and helped to clarify some problems not connected with defining. This included helping some first-graders write down answers as they were not able to write on their own. Teachers did not take part in the testing. It took children from half an hour (for fifth-graders) to one hour (for first-graders) to complete the test. All the children completed the test. Grade 1 consisted of 24 7–8-year-olds; grade 2, of 15 9–10-year-olds; grade 4, of 22 11–12-year-olds; and grade 5, of 22 11-year-olds.

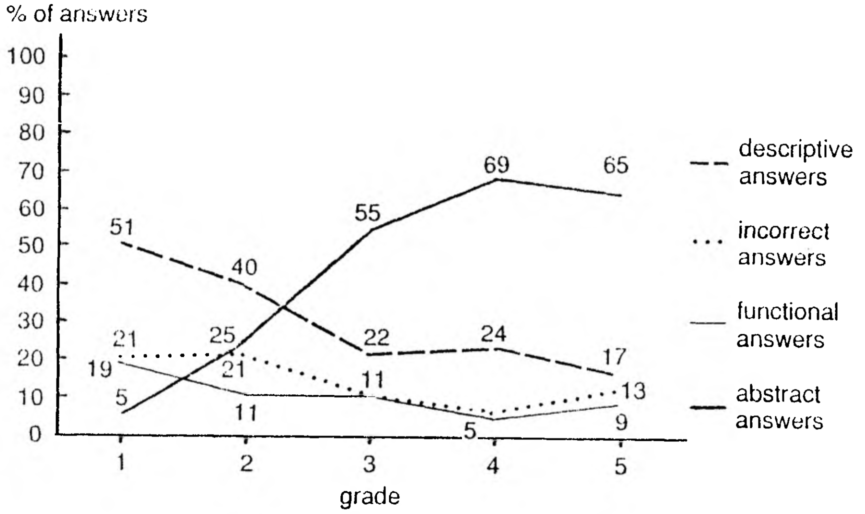

Figure 1. The relationship between definition type and grade.

Results

The responses were organized according to the most widespread classification of definitions: (*1*) abstract, conceptual, or semantic definitions (by genus or, more exactly, by specific differences); (*2*) functional definitions (the function of an object is given); (*3*) descriptive definitions (external features of an object are described, the concept is specified, an example is given, or a concrete situation is described in connection with the object); (*4*) incorrect definitions (no answers, incorrect answers, or excessively broad definitions). The results of the test are shown in Figure 1.

As can be seen, abstract defining began to predominate in the third grade (i.e., from the age of nine or ten years). This is consistent with the literature, which has shown the turning point from nonabstract to abstract definitions at about age nine.

Some decline in the role of abstract definitions in our fifth-grade sample may be explained by the fact that teachers considered the fourth-graders in question more successful in their studies than the fifth-graders.

It was mentioned earlier that the distribution of descriptive and functional definitions has not been unequivocally delineated. In the case of our children, there were more descriptive definitions than functional ones. This may be related to the fact that in our test we used many words that represent abstract concepts, and the objects to which the names of these concepts referred were difficult to find a function for (e.g., melting). However, it should also be pointed out that very few functional definitions were given to the concepts of objects with seemingly important functions for children (e.g., "winter/to ski and sled," "lake/to swim").

Shifts in the nature of descriptive definitions not described in the literature became evident as well. Just as the role of abstract definitions was different in the first through second and third through fifth grades, the descriptions in these grades were different as well. The first-graders' associative rather than descriptive answers (e.g., "air/wind") are replaced by more thorough (scientific) explanations of phenomena or objects (e.g., "air/natural resources; atmosphere"). The most evident description shifts are seen among natural science objects and phenomena (melting, water, ice, bat, bee, winter, river, the earth, the sun, day and night). However, there are no such differences in the descriptive definitions of concepts that have a good prototype (e.g., "liquid/water") or essential function (e.g., "eye/to see"). It was characteristic that thorough descriptions were given only to natural objects and phenomena. In mathematics the corresponding shift was from associative answers to abstract definitions. Here differences are seen between natural sciences and exact sciences (see above).

Testing the Vygotskian hypothesis

To test the Vygotskian hypothesis, we compared the development of abstract definitions of three types of concepts: everyday (orange, blueberry, apple, bicycle, bee), natural science (melting, river, the sun, air, liquid), and mathematical (minute, meter, weighing, measuring, square). The results of this comparison are shown in Figure 2.

It is evident that more abstract definitions are given to the everyday concepts. While this holds true even for the first grade, even greater differences are seen in grades three through five, where abstract definitions generally predominate. Abstract definitions were given to 80%–90% of the everyday concepts, in contrast to only 36%–55% of scientific concepts. Our results do not confirm the Vygotskian hypothesis of the developmental advantage of conscious awareness for scientific concepts compared with everyday ones. The children did not pared with the everyday ones. We did not find a "downward" development of concepts learned in school (but unknown to children from everyday life). Instead, our child subjects displayed poor knowledge of their abstract definitions (see Figures 2 and 3). In our society, school knowledge does not develop separately from everyday knowledge, as has been reported in so-called traditional societies. We cannot differentiate concept domains such as everyday versus scientific so clearly. It is better to talk about the development of a new type of—scientific—thinking and connect it with school activities (see [22]). Scientific thinking is shaped in school, but on the basis of well-known (everyday) concepts.

To explain our results, we make use of Vygotsky's notion of the ZPD (see above). He wrote about scientific concepts as belonging to the level of actual development and about everyday concepts as belonging to the level of potential development. We did not find scientific concepts at the level of actual development (i.e., "downward" development). Instead, we found (from the comprehension test) abstract definitions of everyday concepts within children's ZPD. Children, however, do not actively use these definitions before grade three. They consider striking features and function more essential than the abstract scientific definition. Our studies showed that the concepts known passively and earlier by children were defined abstractly by them earlier, but only when abstract definitions were being stressed and this knowledge was demanded in school, i.e., with the help of teachers. We should therefore argue that children first acquire scientific knowledge incidentally and are not consciously aware of its later usefulness.

When the scientific system is demanded in school, conscious awareness of the concepts (whose definitions are at the level of potential development) proceeds more easily. It is seen both in an increase in the amount of abstract definitions and in the production of more thorough descriptions. The actualization takes place with the help of teachers in school. The cultural background of the fact that abstract definitions begin to dominate from the third grade on can be found in school materials. Emphasis on systematic scientific knowledge and defining starts specifically in the third grade. In the first two grades, the main emphasis in mathematics is on teaching addition and subtraction, and in natural science studies (in which these descriptions are given by external domains, not by scientific ones), on describing natural phenomena.

Conclusions

In this paper we have examined, theoretically and experimentally, problems of word definition development in children. In contrast to earlier studies, our tests were developed on the basis of data acquired by analysis of schoolbooks. Our aim was to compare the development of everyday and scientific concepts and to study the impact of formal education on defining.

We did not find a developmental advantage in conscious awareness of scientific concepts compared with everyday ones. It became evident that Vygotsky's theoretical views need specifying in our (modern) society, in which children become acquainted with definitions before they enter school. Earlier researchers, confirming the developmental advantage of conscious awareness of scientific concepts compared with everyday ones, have carried out their studies in societies in which the main, and nearly only, source of scientific knowledge was really the school. However, our society is so "permeated" with science that we cannot confine scientific concepts to those taught in school.

We found that schoolchildren defined better (i.e., gave more abstract definitions to) those words that kindergarteners recognized accurately by their definitions (i.e., specifically, everyday concepts). We explain this finding by using Vygotsky's notion of the ZPD: initially children begin to define abstractly words whose abstract definitions are within their ZPD. Still to be investigated is how that potential knowledge is actualized in classrooms. The present study opens the door to such future research.

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II

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12 Voices of thinking and speaking

James V. Wertsch, Fran Hagstrom, and Eve Kikas

Over the course of her career Sylvia Scribner made numerous contributions to our understanding of how human activity is related to psychological functioning. Her focus on activity is most explicit in the ingenious analyses she conducted near the end of her career on cognitive processes in the workplace, analyses that were specifically grounded in the theory of activity outlined by Leont'ev (1981) and others. In our view, however, Scribner made major contributions to what may be termed an activity oriented approach to psychology even before she began explicitly grounding her claims in the writings of activity theorists. For example, her decades of work on the relationship between literacy and psychological processes are perhaps best understood in terms of what she and her colleagues came to call a "practice account of literacy" (Scribner & Cole 1981, p. 235). This and other earlier research concerned with literacy, language, and thought focused consistently on how "socially organized activities may come to have consequences for human thought" (p. 235). In one way or another, then, much of Scribner's research can be viewed as being grounded in the assumption that the study of human mental functioning is best approached from the perspective of socioculturally situated activity.

In an attempt to explicate the forms of activity Scribner considered in her studies of literacy we shall harness the notion of "mediated action" (Wertsch 1991; Zinchenko 1985). Our use of this notion reflects the intellectual heritage we share with Scribner, a heritage grounded in the works of authors such as Vygotsky (1977, 1978, 1981, 1987), Leont'ev (1981), Tulviste (1991), and Zinchenko (1985). The primary claim at

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issue here is that the use of "mediational means," or "tools" such as language shapes human action in essential ways. According to Vygotsky, "by being included in the process of behavior, the psychological tool [i.e., one form of mediational means] alters the entire flow and structure of mental functions. It does this by determining the structure of a new instrumental act, just as a technical tool alters the process of a natural adaptation by determining the form of labor operations" (1981, p. 137). When considering literacy practice as mediated action, the mediational means employed are the forms of language used in this activity setting, and the issue is how these mediational means are actively employed by humans such that they are appropriated, or incorporated into concrete action, thereby shaping the form this action takes.

One of the major contributions Scribner and her colleagues made to our understanding of literacy is that language is incorporated into action in a variety of ways, reflecting a variety of sociocultural settings and resulting in a variety of literacy practices (e.g., Scribner 1977; Scribner & Cole 1981). The roots of this claim can be found in the writings of Vygotsky (1977, 1978, 1981, 1987) about the role of "technical" and "psychological" tools in organizing human mental processes, but it goes beyond Vygotsky's formulation in its analysis of the range of cultural, historical, and institutional contexts that shape mediational means and hence human action.

In general, Vygotsky did not carry out detailed analyses of sociocultural context. He was only beginning to devote attention to this issue near the end of his life. This becomes apparent if one considers differences between chapters 5 and 6 of *Thinking and Speech* (1987). Chapter 5, "An experimental study of concept development," was probably written sometime in the early 1930s. In it Vygotsky reported on research he had conducted with Sakharov (1930) in the late 1920s. Chapter 6, "The development of scientific concepts in childhood," was written specifically for the volume *Thinking and Speech*, which was published in 1934.

Although both chapters are concerned with concept development, there is a major difference between them in how this development was viewed as taking place. Chapter 5 deals with concept development in terms of individual mental functioning as measured in a clinical experimental setting. Results from the Vygotsky–Sakharov block-sorting task were used to document the nature of various kinds of complexes and the transition to pseudoconceptual and conceptual levels of functioning.

In chapter 6, the concern with concept development continues to occupy center stage, but there is an important shift to considering concept development in terms of how it is tied to forms of discourse in a specific institutional context, namely, formal schooling. This shift is reflected in the terminology Vygotsky employed. In contrast to chapter 5, where he wrote of "complexes," "pseudoconcepts," "genuine concepts," and other constructs that apply to individual mental functioning, chapter 6 deals with "scientific concepts," a term Vygotsky had not employed in the previous chapter. The Russian word involved here *nauchnyi* can also be translated as "academic" or "scholarly" instead of "scientific;" the term "scholarly" actually being used in the English translation of one of Luria's works (Luria 1976).

This shift in Vygotsky's terminology reflects a more general shift in focus and a growing concern with how specific forms of mediated action are tied to the institutional context of the classroom. His focus had expanded beyond individual ("intramental") as well as dyadic or small group ("intermental") functioning construed in a narrow way. In place of searching for the social origins of individual mental functioning solely in intermental processes, he was concerned with how individual and social processes are situated in a broader sociocultural context. Scribner extended this line of inquiry in her studies of literacy and workplace activities. In both realms her research led her to identify important differences in socioculturally situated, material practice. For example, her studies of literacy led her to conclude that rather than being a monolithic essence or process, literacy activity and the psychological processes associated with it take on various forms and that these forms reflect aspects of the institutional settings in which they appear.

Modes of thinking and ways of speaking

One of Scribner's most interesting analyses of how forms of speaking and thinking are tied to activity settings can be found in her chapter "Modes of thinking and ways of speaking: Culture and logic reconsidered," which appeared in the 1977 edited volume *Thinking: Readings in Cognitive Science*. Based on her review of numerous studies of differences between schooled and nonschooled subjects in solving verbal logic problems (typically syllogisms), Scribner concluded

the overall level of performance of nonschooled traditional people and the within-culture differences in performance between schooled and nonschooled groups suggest that logical problems pose special difficulties for traditional nonliterate people. Uniformities in patterns *across* cultures indicate that the source of these difficulties is not likely to reside in aspects of culture that are unique to any one of the given cultures. (1977, p. 487)

In trying to account for the sources of the consistent differences she found between schooled and nonschooled peoples, Scribner turned to the notions of genre and performance as outlined by Hymes (1974).

[G]enre refers to stylistic structures or organized verbal forms with a beginning and a end, 'and a pattern to what comes between. '. . . Greetings, farewells, riddles, proverbs, prayers, are among well-known elementary genres, and tales and myths representative of complex genres, *Performances* refers to the use of genres in particular contexts. Both genres and performances may vary from one speech community to another, and the relationship between them may vary as well: certain genres in certain communities may be context-bound while in others they range over diverse events and situations. (Scribner, 1977, pp. 497–498)

The specific issue that concerned Scribner in her analysis of literacy activities and their psychological correlates was the nature of what she termed the "logical genre."

Let us entertain the proposition that verbal logic problems . . . constitute a specialized language genre that stands apart from other genres in ways that may be difficult to define but are readily recognizable (just as poetry may be distinguished from prose by readers who may never exactly agree on what 'poetry' is). (Scribner 1977, p. 498)

In developing her account of the logical genre Scribner was dealing with a specific form of what we are calling mediated action and with the more general issues of a theory of activity. The mediational means involved are the genres or "organized verbal forms" used by participants in her studies, and the concrete instantiation of these mediational means occurred in the form of performance, the "use of genres in particular contexts." Furthermore, Scribner made a series of claims about how the form that mediated action takes is related to the activity setting in which is appears. All this points to the idea that even though Scribner was not explicitly formulating her claims in the 1970s in terms of a theory of activity, she had important insights into what would constitute an activity-oriented approach and this approach played a major role in determining what she saw as research issues and how she approached them.

Voices, genres, and modes of speaking and thinking

In recent years, a figure who has come to be recognized as a major contributor to our understanding of the motion of genre is Mikhail Mikhailovich Bakhtin (1981, 1984, 1986; see also Clark &

Holquist 1984; Todorov 1984). Although Bakhtin was not in search of a Marxist approach to psychology, and although there is no indication that he was in direct contact with Vygotsky, his ideas provide extremely valuable complements and extensions of Vygotsky's notion of mediation (Wertsch 1991). Of particular interest for our purposes is Bakhtin's notion of "speech genre."

When writing of speech genres, Bakhtin was specifically focusing on *speech*, which occurs in the form of *utterances*, in contrast to linguistic forms (e.g., sentences) abstracted away from the form of action he called "speech communication." This focus on speech as action rather than on linguistic structures abstracted out of action also characterized Vygotsky's writings, a point that is sometimes overlooked because of the mistranslation of the title of his best known volume as *Thought and Language* instead of *Thinking and Speech*.

Bakhtin insisted that an adequate account of speech communication could be derived only by focusing on "the *real unit* of speech communication: the utterance" (1986, p. 17) since "speech can exist in reality only in the form of concrete utterances of individual speaking people, speech subjects" (1986, p. 71). In his view an essential key to understanding the nature of utterances is recognizing a level of organization between abstracted linguistic form or structure, on the one hand, and unique, contextualized utterances, on the other. This is a level that has been largely missing in linguistic analysis since Saussure. As Holquist (1986, p. xvi) has noted

> Saussure conceived the individual language user to be an absolutely free agent with the ability to choose any words to implement a particular intention. Saussure concluded, not surprisingly, that language as used by heterogeneous millions of such willful subjects was unstudiable, a chaotic jungle beyond the capacity of science to domesticate.
>
> Bakhtin, on the other hand, begins by assuming that individual speakers do not have the kind of freedom *parole* assumes they have: the basic unit for the study of actual speech practice is the "utterance," which "with all its individuality and creativity, can in no way be regarded as a *completely free combination* of forms of language, as is supposed, for example, by Saussure . . . who juxtaposed the utterance (*la parole*) as a purely individual act, to the system of language as a phenomenon that is purely social and mandatory for the individual."

The intermediate level of organization that Bakhtin proposed in order to deal with this issue is to be found in categories of utterance categories, or types such as speech genres. Speech genres are "relatively stable and normative forms of the utterance" (1986, p. 81). It is this level of organization that makes it the case that the utterance, with all its properties of individuality and uniqueness, is nonetheless not a "*completely free combination* of forms of language" (Bakhtin 1986, p. 81). According to Bakhtin (1986, p. 87)

> A speech genre is not a form of language, but a typical form of utterance; as such the genre also includes a certain typical kind of expression that inheres in it. In the genre the word acquires a particular typical expression. Genres correspond to typical situations of speech communication, typical themes, and, consequently, also to particular contacts between the *meanings* of words and actual concrete reality under certain typical circumstances.

There are many similarities between Bakhtin's treatment of speech genre and utterance and the account of genre and performance, which Scribner invoked to develop her notion of a logical genre. As is the case in Hymes's account, Bakhtin's approach emphasizes that genres are associated with particular kinds of situations. This, of course, was an essential point for Scribner in her attempt to deal with the fact that the logical genre is so closely tied to experience in a particular institutional setting – formal schooling. It is the mediating role of genres that creates the link between individuals' performances or utterances on the one hand and institutional settings on the other. Furthermore, both Bakhtin and Hymes focus on the tension between a genre, which is "impersonal" (Bakhtin 1986, p. 88), and the utterances produced by appropriating a genre. Every utterance occurs in a unique way in a concrete setting and hence has personalized and contextualized properties specific to it and it alone.

The essential contribution Bakhtin's ideas make to this general line of inquiry derives from his account of "dialogism." As authors such as Holquist (1990) and Todorov (1984) have noted, dialogism, or dialogicality, is the most fundamental theoretical construct in Bakhtin's approach. It is a notion that is analytically prior even to that of the utterance or voice since the production of utterances always involves a speaker's appropriating, invoking, or ventriloquating through the voices of others, thereby entering into a dialogic encounter with them. The fundamental Bakhtinian question is, Who is doing the speaking?, and the fundamental Bakhtinian answer is, At least two voices. This claim about "multivoicedness" comes through very clearly in Bakhtin's (1986, p. 78) comments on speech genres.

> We speak only in definite speech genres, that is, all our utterances have definite and relatively stable typical *forms of construction of the whole.* Our repertoire of oral (and written) speech genres is rich. We use them confidently and skillfully *in practice*, and it is quite possible for us not even to suspect their existence *in theory*. Like Moliere's Monsieur Jourdain who, when speaking in prose, had no idea that was what he was doing, we speak in diverse speech genres without suspecting that they exist. Even in the most free, the most unconstrained conversation, we cast our speech in definite generic forms, sometimes rigid and trite ones, sometimes more flexible, plastic, and creative ones.

In this view it is no more possible to produce an utterance without invoking a speech genre than it is possible to produce an utterance without invoking a "national language" such as English, French, or Thai.

The resulting picture is one in which speaking is inherently a process of appropriating the words of others, be they concrete, identifiable other individuals or groups of others, as in the case of "social languages" (Wertsch 1991). Speech is therefore a form of mediated action in which speech genres (along with other aspects of language) serve as mediational means. As is the case with all forms of mediated action (Wertsch 1991) this implies that there is an inherent and irreducible tension between the mediational means, that is, an "impersonal" tool, on the one hand, and the unique and personal use or instantiation of this tool in a concrete performance, on the other. In Bakhtinian terms

> Our speech, that is, all our utterances (including creative works), is filled with others' words, varying degrees of otherness or varying degrees of "our-own-ness," varying degrees of awareness and detachment. These words of others carry with them their own expression, their own evaluative tone, which we assimilate, rework, and re-accentuate. (Bakhtin 1986, p. 89)

Speech genres and the logical genre

A complete account of the implications of Bakhtin's claims for Scribner's account of literacy would need to address two basic issues. First, it would need to produce a more complete explication of speech genres in general and of the genres associated with literacy in particular. What are the specific properties of speech genres used in literacy practice? How do they differ from other speech genres? Second, the problem of how these speech genres can be appropriated in unique performances needs to be addressed. What processes are involved in invoking or ventriloquating through a speech genre in order to produce concrete utterances? How do these processes vary depending on contextual factors?

These two research agendas may be distinguished analytically and hence investigated, at least to some degree, independently. This is so even though they must eventually be related in order not to lose sight of the irreducible connection between mediational means and their use, a point Bakhtin was alluding to in his critique of traditional linguistic analyses when he noted that "speech can exist in reality only in the form of concrete utterances" (1986, p. 71). In what follows, we shall focus primarily on issues of mapping out the properties of speech genres used in literacy practice and spend less time on the dynamics of their use (for the latter, see Wertsch & O'Connor, 1994). In particular, we shall be concerned with ways in which Scribner's "logical genre" might shape speaking and thinking processes.

On the basis of her review of several studies of verbal logical problems, Scribner (1977) argued that the major difference between schooled and nonschooled participants was that the former tended to use only that information explicitly provided by the experimenter, whereas the nonschooled participants' answers often reflected a tendency to take other information into consideration.

> The critical factor [in the performance of the nonschooled subjects] is that the 'evidence use by the subject', in many cases . . . bore little resemblance to the evidence supplied in the experimental problem. Cole et al. (1971, p. 188) concluded: 'The subjects were (or seem to have been) responding to conventional situations in which their past experience dictated the answer. . . . In short, it appears that the particular verbal context and content dictate the response rather than the arbitrarily imposed relations among the elements in the problem.' (Scribner 1977, p. 488)

Further analyses by Scribner suggest that the pattern of nonschooled subjects' performance was *not* attributable to faulty logical procedures or logical procedures that were even qualitatively distinct from those employed by the schooled subjects. Instead, the differences between schooled and nonschooled participants derived from different patterns in what they took to be the content on which operations were to be performed.

In her analysis of studies that specifically asked participants to justify or explain their answers, Scribner employed a distinction between "theoretical" and "empirical" explanations. Theoretical explanations were defined as being based strictly on information supplied by the experimenter, whereas empirical explanations were defined as being based on information that the subjects themselves introduced. As an example of this distinction Scribner gives the following problem and types of explanation:

> All people who own houses pay a house tax.
> Boima does not pay a house tax.
> Does Boima own a house?
>
> A theoretical justification: 'If you say Boima does not pay a house tax, he cannot own a house.' An empirical explanation: 'Boima does not have money to pay a house tax.' (1977, p. 489)

Scribner found that by incorporating the distinction between empirical and theoretical explanations into the analysis of data from several studies the differences between schooled and nonschooled participants became even more pronounced:

> Nonschooled villagers overwhelmingly support their answers by appeals to fact, belief or opinion [i.e., facts known to them but not explicitly stated by the experiment]. . . . This appeal to real world knowledge and experience, which for the time being we will call 'empirical bias', is the single most prominent characteristic of villagers' performance. (1977, pp. 489–490)

As Scribner notes, an empirical bias does not disappear completely from the reasoning of even very highly educated individuals. Furthermore, she was certainly not implying that it *should* disappear from the thinking processes of individuals as they go about their everyday business in a variety of activity settings, only one of which may be formal schooling. Instead, the implicit claim is that the logical genre is one tool in a "cultural tool kit" (Wertsch 1991) that emerges in response to participating in certain activity settings. Instead of replacing other cultural tools, or mediational means, the emergence of the logical genre is more likely to add to the "heterogeneity" (Tulviste 1991) of this took kit, a heterogeneity that reflects the "activity relativism" (Tulviste 1991) of sociocultural settings in which humans live.

In the particular case of Scribner's logical genre, a defining property of the mediational means is a distinction between what we shall term "activated" and "nonactivated" information. When schooled participants invoked the logical genre to solve syllogisms, activated information was defined as that information which has been explicitly stated by the experimenter. Nonactivated information was any other information known to either the experimenter or subject or both, but information that had not been made known through the explicit statements of the experimenter. In this particular context, because it was not made known through such explicit assertions, it was deemed irrelevant to the task.

At first glance it might appear that the distinction between activated and nonactivated information is grounded in an objective assessment of what information is available (through explicit statements or otherwise) to the interlocutors in a context. Such a view would parallel assumptions that underlie accounts of given versus new information (Halliday 1967; Chafe 1974, 1976; Clark and Haviland 1977), psychological subject versus psychological predicate (Vygotsky 1987), and so forth. In these accounts the focus is on how information is established in consciousness or in the context of speaking and how this "given information" is then used as the foundation for interaction.

It is certainly true that knowledge of given information plays a role in producing and understanding utterances and is a necessary factor in determining what counts as activated information. Specifically, if something is not given information – the psychological subject, the theme, and so forth – it cannot be activated information. However, *not all given information is activated* in the sense of "activated" that we are using. The distinction between activated and nonactivated information differs from the others in an essential way. This is because the distinction between activated and nonactivated information is grounded not only in what information is available for one reason or another in a discourse setting, but in the speech genre as well. That is, *specific speech genres entail specific assumptions about what is activated and nonactivated information*, and this fact often operates independently of whether or not the interlocutors in a speech context share knowledge of certain information.

The difference we are talking about here concerns relationships between utterances and their contexts. On the one hand, utterances must occur in some already existing context and as a result have certain presuppositions. Notions such as given information, psychological subject, and theme are grounded in this observation. On the other hand, making an utterance defines or transforms this context in some way. This is the "performative" or "creative" dimension of speaking analyzed by theorists such as Austin (1962) and Silverstein (1976, 1985). The specific claim we wish to make derives from the observation that producing an utterance involves a speech genre and any speech genre shapes the creative dimension of utterances in certain ways. Of particular interest at this point is that the invocation of a particular speech genre carries with it a specific assignment of activated and nonactivated information, and this assignment may be independent of the given-new distinction.

As an illustration of this claim, consider the examples reviewed by Scribner in her account of what she called the logical genre. The major difference between schooled and nonschooled participants in the studies she reviewed was that the former were more likely to operate solely on the basis of activated information (in this case defined as information explicitly provided by the experimenter), whereas the nonschooled participants tended to take other information into account. The fact that activated information is defined in the context of this speech genre as that information explicitly provided by the experimenter cannot be reduced to facts about what the experimenter and subject knew in general and how their knowledge overlaps. For example, in the case of the syllogism about Boima, both the experimenter and subject may have in fact known that "Boima does not have money to pay a house tax" (Scribner 1977, p. 489). However, by invoking the logical genre, this shared background knowledge is not defined as activated information and hence is deemed irrelevant when drawing a conclusion.

Scribner's "theoretical" explanations are associated with invoking her logical genre and hence using activated information as defined by this genre, whereas "empirical" explanations are associated with using nonactivated information (in some cases alongside activated information). Similarly, the definition of the "empirical bias" derives from the distinction between activated and nonactivated information, and again this distinction is grounded in the invocation of the logical genre and not from some distinction between types of information, which has an independent, objective existence. The mastery of this genre therefore involves mastery of a particular distinction between activated and nonactivated information.

The essential point here is that the difference between activated and nonactivated information is not grounded in some objective property of the information itself. Instead, it is grounded in the properties of the speech genre used to carry out the mediated action at issue. By invoking the logical speech genre, one creates a very circumscribed discourse space in which certain information is defined as irrelevant independently of what the interlocutors might actually know or share as background information. As a result, what counts as an empirical explanation cannot be determined by analyses of information that do not take into account the particular distinction between activated and nonactivated information entailed by the particular speech genre at issue. In cases involving Scribner's logical genre, this means that information invoked to produce an empirical explanation could have produced a theoretical explanation *if* it had been explicitly stated by the experimenter rather than deriving from some other source.

The logical genre and literacy activity

As we argued earlier, Scribner was utilizing a kind of activity-oriented approach to issues in literacy several years before she explicitly invoked ideas and terms from others' activity theories. In our view much of her career was devoted to developing an activity theory approach to a range of phenomena. In general, this approach was grounded in the claim that mental processes of individuals can be understood only by understanding how they fit into culturally, historically, and institutionally situated activity. Scribner pursued this claim by examining concrete forms of practice, or action, with one eye toward their psychological correlates and the other toward the sociocultural settings in which they occurred. As noted earlier, this line of reasoning is consistent with the perspective Vygotsky was developing near the end of his career when he expanded his notion of scientific concepts to say that such concepts must be understood in terms of their role in discourse peculiar to formal instructional settings rather than in terms of more narrowly defined social processes.

Given this context of concerns and issues, Scribner's account of the logical genre can be seen to have major implications for how we can understand literacy activity. Specifically, it raises the question of what it is in literacy practice that might lead to differences between schooled and nonschooled people's approaches to syllogistic reasoning. Neither Scribner nor others have argued that it is extensive practice with tasks that are explicitly organized in syllogistic form that has this effect. With a few possible exceptions (e.g., story problems in mathematics), there seem to be few direct parallels between the requirements of syllogistic reasoning tasks and those of ongoing literacy practices in the classroom.

Instead, we would argue that the patterns of using the logical genre Scribner found derive from extensive experiences with various forms of the distinction between activated and nonactivated information. In contrast to the relatively simple and clear distinction entailed when invoking the logical genre to solve syllogisms (a distinction grounded in what has been explicitly stated in the immediate context), this distinction is often less simple and less clear in classroom discourse. However, it is no less strongly imposed. This latter fact is an indication that it has one of the major properties of a cultural tool, or mediational means, in an account of mediated action. It is socioculturally situated in the sense that it is preferred, or "privileged" (Wertsch 1991), over others in a particular cultural, institutional, and historical setting.

In contrast to the experimental settings reviewed by Scribner (1977), the distinction between activated and nonactivated information in classroom discourse does not rest on whether something has been explicitly stated in the immediate context. Instead of this relatively simple and clear criterion for making the distinction, the speech genres found in classroom discourse tend to be grounded in a more general distinction between activated and nonactivated information. It is certainly true that something may be activated information by virtue of its just having been stated, but many other criteria seem to be used as well. For example, information that has been covered in previous classroom discourse, information that comes from shared background reading, and information from other sources that are presumed to be shared all may qualify as activated information.

However, as in the case of Scribner's logical genre, the distinction between activated and nonactivated information cannot be reduced to what is shared background and what is not. It always involves the element of contextual creativity or performativity, and what is created is conventionally associated with the speech genre. Thus, to master a speech genre is to master a particular distinction between activated and nonactivated information.

The specifics of this line of reasoning are obviously still in the process of being worked out. However, the general framework of the argument has begun to emerge quite clearly, thanks to the insights of scholars such as Scribner. Indeed, Scribner's career can be understood as a continuing attempt to address the complex issues of a theory of activity that would allow us to understand relationships between human mental processes and sociocultural setting. For her, a starting point was the claim that human mental processes are best understood in terms of human action. Given that such action always occurs in cultural, institutional, and historical contexts, she was constantly led to address the issue of how mental functioning is inherently socioculturally situated.

Scribner's elaboration of these claims generated insights that will be the focus of research and action programs for years to come. The fact that her ideas continue to appeal to people from such an array of professional and cultural backgrounds speaks volumes about the ingenious insights she brought to her work. Perhaps even more importantly, this appeal reflects the deep commitment she had to respecting the perspectives of the weak as well as the powerful. Her convincing demonstrations that there is more than one intelligent way to understand the world around us provides an important starting point for pursuing one of her deepest desires – to make the world a better place for all of us.

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III

Kikas, E. The impact of teaching on students' definitions and explanations. (submitted)

THE IMPACT OF TEACHING ON STUDENTS' DEFINITIONS AND EXPLANATIONS

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A longitudinal study of the influence of education on children's ability to define and explain astronomical concepts (equator, axis, orbit, day/night variations and seasonal changes) was carried out. An initial analysis was conducted of the way the topics were covered in the textbook and taught in the classroom. Subsequently twenty students (aged 10–11 years) were interviewed two months after being taught the topics and again four years later in order to establish the impact of the teaching on their ability to define and explain the concepts correctly. The results indicated that after two months the students were able to recall the scientific explanations given in the lesson and the textbook but that after four years they could only give "everyday" non scientific and inaccurate explanations.

Introduction

This longitudinal investigation was aimed to determine the influence of education on children's definitions of astronomy concepts (equator, axis, orbit) and explanations of phenomena (day/night variation and seasonal changes) over time. Astronomy is a field where everyday models differ quite substantially from scientific explanations of physical phenomena. Therefore, they are good indicators of the interface between the two.

We could show the strong impact of teaching on students' definitions and explanations shortly after learning the topics in school. But students only memorized the school knowledge without integrating into their everyday knowledge and returned to everyday explanations 4 years later.

The impact of education on thinking

Logical arguments and well- defined conceptual systems are characteristic of scientific thinking. It has been shown that scientific thinking does not develop without schooling (Luria, 1976; Tulviste, 1991; Scribner & Cole, 1981). Different reasons for this development have been offered.

Essentially schooling occurs through the medium of verbal instruction and therefore falls outside everyday personal experiences. Therefore, as Tulviste writes: "Supra-empirical connections are possible (and obligatory) between scientific concepts themselves but not between their referents" (1991, p. 162). Verbal explanations and logical arguments are of great importance in school (Vygotsky, 1962; Wertsch, 1991). As exact usage of terms is necessary to solve school (scientific) tasks, students have to understand abstract definitions (Kikas, 1993; Tulviste, 1991). Definitions make explicit the implicit meanings underlying the use of words in ordinary discourse, and this explicit meaning can be analyzed and revised. Also, causal explanations and logical arguments are used in scientific discussions and also in school. Many studies have shown that the extent to which children can use abstract terms to define concepts grows with age (e.g., Benelli, Arcuri & Marchesini, 1988; Kikas, 1993; Markowitz & Franz 1988; Watson, 1985). If there is no need in later life to solve such problems, scientific thinking (including the ability to define abstractly) may decline (Luria, 1976; Rabinovitz & Mandler 1983; Tulviste, 1991).

A specific speech genre — the language of "official science" (Wertsch, 1991; also called the "literate register", Watson, 1985; Snow, 1990) — should be used in school. Students learn to speak in this new genre. Several researchers make use of the idea of "talking science": students should be able to talk science to be able to participate in scientific discussions (Howe, Tolmie & Rodgers, 1992; Lemke, 1990). Lemke argues: "Classroom language is not just a list of technical terms, or even just a recital of definitions. It is the use of those terms in relation to one another, across a wide variety of contexts. Students have to learn how to combine the meanings of different terms according to the accepted ways of talking science" (1990, p. 12). Descriptions of phenomena are used as far as phenomena are directly observable but explanations of unobservable entities become important in scientific language. Abstract definitions are also characteristic of the language of official science (Wertsch, 1991) or talking science (Lemke, 1990). So, while learning in school, students are urged to talk in a language of "official science". Accordingly, their ability to define abstractly and use logical arguments should improve.

Children's naive theories and science education

Recent studies have shown that children's knowledge falls into (naive) theories (mental models) (Carey, 1985; Keil, 1989; Neisser, 1987; Vosniadou, 1992; Vosniadou & Brewer, 1994). These models are derived from children's everyday perception. It has been argued that their structure is an analogue to the states of the world it represents and that they provide explanations of physical phenomena (Vosniadou & Brewer, 1994).

Scientific knowledge consists of representations of natural phenomena (in the form of theories, laws, principles) and is taught to children in school. Children's personal knowledge varies in the degree to which it is consistent with scientific knowledge (Glynn & Duit, 1995). In fact it appears that young children's mental models are very difficult to change in school especially if they essentially differ from scientific explanations and therefore radical knowledge restructuring is inevitable (Chi, Slotta & Leeuw, 1994; Driver, Guesne & Tiberhgien, 1985; Neisser, 1987; Vosniadou, 1992; Vosniadou & Brewer, 1994; White, 1983). It has been found that essentially children learn from school the knowledge that does not contradict their everyday experiences. Sometimes they make a compromise, forming synthetic models (also called misconceptions): "They change their mental models in a way that allows them to retain as many as possible of their experiential beliefs without contradicting adult teachings" (Vosniadou, 1992, p. 352). Cognitive scientists have paid little attention to the exact reasons why knowledge restructuring had not occurred during learning and have not studied textbook and lesson discourse.

In contrast the impact of instruction and teaching methods has been studied extensively in educational psychology. Initially these studies were based on the need to improve science education.

There has been a widely held view in education that the textbook plays a dominant role in science teaching (i.e., science curriculum is textbook-centered) (Stinner, 1995).

These textbooks emphasize memorizing new information (facts, definitions, explanations) and learning answers rather than exploring questions (Stinner, 1995; Glynn, Yeany & Britton, 1991; Michaels & Bruce, 1989). It has been shown that this new information does not take into account students' previous (naive) conceptions (Michaels & Bruce, 1989; Renner, Abraham & Grzybowsky, 1990). The textbooks' explanations are usually so inadequate, sometimes with logical contradictions, that it is impossible to learn from the text alone (Michaels & Bruce 1989; Pizzini, Shepardson & Abell, 1992).

In their instruction and teaching, teachers heavily rely on the textbook (Stinner, 1995; Driscoll *et al.*, 1994; Yore, 1991). Traditional textbooks encourage the teachers to use the instructional mode of lecture, question, and answer. Teachers deliver the facts, definitions and explanations and the students' task is to memorize them in order to know the answer to the evaluative questions. The question is whether such kind of teaching is enough to produce meaningful learning and real understanding of the phenomena.

The benefits of more student-centered (or student-active) forms of teaching and learning have been shown (Gillies & Ashman, 1995; Bergqvist & Säljö, 1994; Wistedt, 1994). The meaningful learning of science involves active constructing of conceptual models by relating new knowledge to existing experiences (Glynn & Duit, 1995). Several studies have shown how learning is maximized if children explore their models (naive explanations) in discussions (with peers) (Howe, Tolmie & Rodgers, 1992; Tolmie *et al.*, 1993).

Mental models and education in astronomy

Children's everyday experience provides them with enough information to develop their own models of astronomical phenomena (e.g., they see the Sun moving in the sky). Even more, the everyday expressions commonly used in Estonia give countenance to the acquisition of these models (e.g., "the Sun rises", "the Sun goes to sleep"). Nowadays theories of astronomy differ radically from the naive models that children construct on the basis of their experience and everyday language usage. In fact theories in astronomy as a scientific discipline have undergone a radical restructuring in the course of the development. There is a noticeable similarity between children's mental models of astronomy and the explanations found in history: young children's mental models are similar to theories used in ancient and medieval times.

Vosniadou and her colleagues have studied the concepts of astronomy beginning from preschool children up to adults. They have shown that the majority of children have well-defined and consistent mental models (Vosniadou, 1992; Vosniadou & Brewer, 1992; Vosniadou & Brewer, 1994). Vosniadou and Brewer (1994) found that 38 students out of 60 (1st, 3rd and 5th graders, 6–11 years old) had coherent day/night variation explanations and used their models consistently. They differentiated within 3 types of models. Initial models are derived and consistent with the observations of everyday life (the Sun is covered by clouds or darkness; day is replaced by night; the Sun goes out at night; the Sun goes behind hills). Synthetic models are the attempts to integrate scientific and everyday information (the Earth goes around the Sun; the Moon blocks the Sun; the Sun moves in the space, the Sun and Moon move; the Earth rotates up/down; the Earth rotates and revolves). Scientific models agree with the view that the Earth spins. They found that 1st graders generally have initial models, during elementary school years they replace it with synthetic models and afterwards with scientific models.

Baxter (1995), studying twenty 9–16 year-old children, also found developmental differences: younger children usually stated that the Sun revolved around the Earth and the older that the Earth spinned. But even 15–16 year olds answered that the Earth revolved around the Sun or the Sun revolved around the Earth. The most popular explanation of seasonal changes was that the Sun was further away during winter.

Sadler (1987), studying twenty five 9th graders, found that the students who were completing a scientific course in astronomy did not give more correct answers than those who were not. Still, they used more scientific terms (orbit, tilt etc). How the topic had been taught in school was not described in his work. Michaels and Bruce (1989) studied 4th grade students' explanations of seasonal changes. They found that after reading the text and having a lengthy discussion and demonstration by the teacher, not a single student learned the correct explanation of what causes the seasons to change. The widespread explanation of the seasonal changes was a "distance theory" (the temperature changes because of the distance between the Earth and the Sun changes), drawn from everyday life (the closer to heat sources the warmer it is). But several students gave personal-narrative explanations (the seasons change because flowers need a rest; we can skate in winter).

Method

Subjects

This investigation was part of a cross-cultural study carried out in collaboration with Michaels and Bruce at the Literacy Institute (Cambridge, MA, USA) — see below stages 1–3[1]. Only the Estonian study was longitudinal: we repeated the interviewing 4 years later — see below stage 4.

Michaels and Bruce gathered data in a typical U.S. multiethnic fourth-grade classroom. As the topics "Day and night variation" and "Seasonal changes" are taught in all Estonian public schools in the 5th grade, we had to do the study in this grade.

Our investigation took place in a usual Estonian secondary school in Tartu (the second largest town in Estonia, population approximately 120 000, 16 schools). The first part of the study (see below, stages 1–3) was carried out in the fall of 1989 in one of the 5th grade classes. There were 22 students (age 10–11) in the class, all of them were interviewed in December 1989. The second interviews took place in December 1994. The same 20 students (grade 9, age 14–15) participated in the interviews, 2 had left the school.

Procedure

The procedure used was as follows:

1. **Analyzing textbook discourse**. We studied the structure and content of the text and the types of exercises that were given in a workbook. Special attention was paid to the ways the terms were defined and phenomena explained.

2. **Analyzing lesson discourse**. The lessons where the topic was studied (grade 5) were observed, videotaped and transcribed.

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[1] We introduced the results of this comparative study in the 5th European Conference on Developmental Psychology in Seville, Spain (6–9 Sept., 1992).

We studied the structure of the lessons and the activities that occurred. We compared the teacher's explanations with the book's version and analyzed the teacher's questions. We looked for the ways students could actively participate in the lessons (ask questions, talk about their experience, use their knowledge).

3. **Interviewing students two months after studying the topic in school**. The interviewer and a student sat alone in a room. The conversation was open-ended and relaxed. The framework of the interview was always the same. The interview began with asking some version of the following questions:

1. What makes the days longer in the summer than in the winter? What makes it hotter in the summer and colder in the winter?
2. If you went south from Tartu (and farther and farther), what would happen to the temperature?
3. When it is summer in Tartu, is it summer everywhere in the world?
4. Why do seasons of the year change?
5. Why do night and day change?
6. What is equator?
7. What is axis?
8. What is orbit?

The interviewer asked frequent follow-up questions ("Say more about that", "What makes that happen?") to be sure that she understood what the students were saying and thinking. Each interview lasted at least 15 minutes.

In this paper, the answers to the last five questions were analyzed because these were the questions (from the above) that were asked by the teacher in the lessons to assess children's factual knowledge.

4. **Interviewing the same students 4 years after studying the topic in school**. The conversation took place in the same room. The framework of the interview was the same.

Results

Teaching the topic in school

Textbook discourse

Astronomy is taught in science lessons. Estonian schools have a science textbook (Nilson & Tiits, 1988) and a workbook (Nilson & Tiits, 1989). The themes "Day and night variation" and "Seasonal changes" are studied as parts of a wider topic "Outer Space". Under this topic, there are 5 subtopics and a summary:

1. Celestial Bodies (2 pages of text with 1 figure and 12 questions; 7 new terms with definitions in the textbook, 4 exercises in the workbook).
2. Planetary System (3 pages, 2 figures, 8 questions, 4 new terms, 3 exercises).
3. Day and Night Variation (3.5 pages, 3 figures, 8 questions, 2 new terms, 6 exercises).
4. Seasonal Changes (3.5 pages, 3 figures, 7 questions, 2 new terms, 7 exercises).
5. The Moon. Exploration of the Outer Space (3 pages, 1 figure, 9 questions, 4 new terms, 5 exercises).
6. Summary (1.5 pages, 24 questions on the whole topic).

The emphasis is on definitions of terms and long descriptions of phenomena. A total of 18 new terms are introduced and defined (including axis, poles, the Earth's rotation and revolution, orbit, equator, the Northern and the Southern Hemisphere). The parts that are stressed are printed in bold and separately. Sixteen definitions including the definitions of axis, orbit and equator are emphasized by bold print. Also, the explanations of seasonal and day/night changes are printed in bold. These definitions and explanations are given in Table 1 by bold print.

Insert Table 1 about here

The book's explanations take into account neither children's naive theories (e.g., that the Sun revolves around the Earth) nor stress the critical knowledge necessary for understanding scientific explanations (e.g., how it is possible that the Earth revolves and rotates but we do not see or feel it).

Lesson discourse

The students studied the whole topic "Outer Space" in the beginning of the 5th grade in the course of 7 lessons.

The lessons' activities grouped into five major blocks: checking the material learnt at home, introducing new material, reading the book, checking the new material, solving the problems. The topics studied, the main activities and their duration (in percentage) in each lesson are given in Table 2.

Insert Table 2 about here

The introduction (16% of lesson on average) was given orally by the teacher. In it, she always briefly retold the text and (if possible) demonstrated phenomena with the help of the globe. The teacher followed the book's explanations very closely.

After this introduction, students had to read the same topic from the textbook. They read silently (13% of all time) and did not ask the teacher any questions.

During checking both the new and learnt at home material (on average 47% of lesson), the teacher asked questions on the topic and students answered. She expected answers to be quite short and the same as in the book. The teacher's talk was much longer than students' answers. For example:[2]

Teacher	Why do we have day and night? What are the reasons of this variation? Who knows? Tom.
Tom	The Earth moves.
Teacher	How does the Earth move? We have talked about several movements. What movement causes the day and night variation?
Tom	Around its axis.
Teacher	Say it once more. The day and night...
Tom	The day and night variate because the Earth moves around its axis.
Teacher	What do we say? How do we name the movements around the axis? It is not a simple movement we say that...
Tom	(No answer)
Teacher	Andy, please.
Andy	The Earth rotates around its axis.
Teacher	Yes, it is called rotation. But is it all? The question was why we do have day and night. What else must we say to explain why we have day and night?
Andy	The Sun shines only to one half of the Earth. Where the Sun shines there is day and where there is no Sun there is night.
Teacher	Yes, that's right.

[2] Children's names have been changed.

The problems from workbook were solved together with the whole class (24% of lesson): the teacher read a task and asked someone to solve it, all the students wrote the answer in their workbooks. The teacher also lectured on the topic when checking the material and solving the problems. So the majority of students had no need to think about the problems, they simply waited for someone to verbalize the answer.

All the lessons were very formal and traditional — as opposed to open ones — (Gaconia, 1987) and teacher-centered — as opposed to learner-centered — (Withall, 1987). Students sat quite passively at their desks, mainly responding to the teacher's questions. The teacher talked to the whole class or asked questions from separate students. Students listened to the teacher's talk, read the book and answered the questions. There was no discussion either between peers or between students and the teacher. Children memorized the book's words. They had no opportunity to compare or integrate the knowledge learnt at school into their personal knowledge. The only question about students' earlier knowledge was "What constellations do you know?" No deeper (scientific) explanation was demanded from children, they had to learn the book's words by heart.

Children's knowledge

Definitions

Students' definitions of the terms "equator", "orbit" and "axis" were analyzed. There are several ways to classify definitions (Kikas, 1993; Litowitz, 1977; Markowitz & Franz, 1988). We divided the definitions into two categories (see Snow, 1990).

1. **More or less correct answers (for short: "correct")**. Here, abstract definitions (also called formal and conceptual) give category (e.g., "Axis is a line..."), in more advanced cases descriptive attributes are added (e.g., "Axis is an imaginary line that goes through the center of the Earth"). Descriptive definitions with hypothetical markers "that" and "which" instead of naming a Superordinate category (e.g., "Axis is that which goes through the Earth") are also included here. In such definitions, the idea is correct, but not the form. Just abstract answers with descriptive attributes were given in the book and generally demanded in lessons. Sometimes, the teacher was satisfied even with descriptive answers.

2. **"Others"** include too broad (e.g., "Axis is tilted a little") and wrong answers but also omissions ("I don't know").

All the students' answers and the number of answers in each category both in 5th and 9th grades are given in Table 1.

It is seen from the table that 5th grade students gave mainly "correct" answers (43 "correct" versus 17 "other" answers). Even more, their answers were mainly those given in the textbook (i.e., giving category relationship with descriptive attributes). The majority of "other" answers were confusing terms (e.g., giving the definition of axis for the orbit). The 9th grade students gave less "correct" and more "other" answers (31 "correct" versus 29 "other" answers). The majority of "other" answers were omissions, i.e. statements "I don't know".

Between-grade changes in students' definition categories were studied. McNemar's chi-square test showed that the change (in "correct"-"other" answers) was statistically significant only for the term equator ($\chi^2(1)=4.17$; $p<0.05$); both other changes are statistically nonsignificant ($p>0.05$). This indicates that there was a consistency over time in the use of either "correct" or "other" answers.

There was a consistency in defining different terms (i.e., using the same category — either "correct" or "other" — answer) by each child. McNemar's test showed that the change was statistically significant only for terms orbit-equator in the 5th grade ($\chi^2(1)=4.2$, $p<0.05$), all other changes were nonsignificant ($p>0.05$). So students tend to use the same category answers in defining different terms.

Explanations

Students' explanations of the reasons for day/night variation and seasonal changes were analyzed. Proceeding from the empirical data, the explanations were divided into five (sub)categories which grouped into two major categories. These latter categories were used in the analyses.

1. **"Earth-movements" (heliocentric)** answers explain the phenomena by the movements of the Earth. Here, **"Exact"** answers contain more or less exact textbook explanation (see Table 1), which was also demanded in the lessons. In **"All"** answers the student relates all s/he remembers, explaining reasons for either day/night variation or seasonal changes (or both) by the fact that the Earth revolves around the axis and around the Sun. In **"Mixed"** answers the student confuses the reasons for day/night and seasonal changes.

2. **"Others"**. Here, **"Sun-movements" (geocentric)(for short: "Sun")** answers give the reason for changes in the Sun rotating around the Earth. It is also a causal explanation but actually wrong: it is taught in school that not the Sun but the Earth revolves around[3]. **Descriptive answers** do not give any causal (physical) reason for the change but describe what can be seen or felt. A "Sun"-explanation is synthetic, descriptive an everyday (initial) explanation (see Vosniadou & Brewer, 1994).

All the students' answers and the number of answers in each category both in the 5th and 9th grades are given in Table 1. It can be seen from the table that 5th grade students explored the textbook's knowledge in their explanations. Overall, there were 35 "Earth-movements" (23 "exact", 4 "all" and 8 "mixed") and only 5 "other" (1 "Sun" and 4 "descriptive") answers. The majority of explanations were like those written in the textbook and demanded in lessons (i.e., "exact"). Explanations were quite similar to each other, more or less in the book's words. Children's answers differed in how well they had remembered the differences between the Earth's rotation around it's axis and around the Sun: some children confused the explanations for day/night and the seasonal changes, some could not distinguish between exact reasons for changes and, therefore, related everything they remembered.

When these students were in the 9th grade, their answers were very different. There were 23 "Earth-movements" (8 "exact", 4 "all" and 7 "mixed") and 17 "other" (14 "Sun" and 3 "descriptive") answers. The mostly used explanation in this grade was "Sun-movements" ("day and night/seasons change because the Sun rotates around the Earth").

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[3] At least, it is wrong in school context. It was stressed many times in the lessons that the Earth revolves around the Sun. According both to Galilean and Einsteinian relativity theory, it is the same either to say that the Earth revolves around the Sun or the Sun around the Earth. But there is a difference between the easiness and convenience in describing these revolutions. Clearly the Sun's revolution alone does not cause day/night variation.

Between-grade changes in explanations were studied. McNemar test showed that the difference was statistically significant for both explanations; $\chi^2(1)=4.17$, $p<0.05$. Reliably more students gave "other" ("descriptive" and "Sun") and not "Earth-movements" explanations answering to the questions "Why do day/night or seasons change" in the 9th grade.

There was a high consistency (i.e., using the same category — either school-based or "other" — answer) in explanations for day/night and seasonal changes in both grades. McNemar's test showed that the change in "Earth-movements"- "other" explanations was nonsignificant in both grades ($p=1.00$). Therefore, students tend to explain both phenomena relatedly, in the same manner, either using "Earth-movements" or "other" explanations (see Vosniadou & Brewer, 1994).

Qualitative analysis

We studied how well students explored their ideas, how consistent they were in their discussions and whether there were qualitative differences between grades. It was found from the interviews that the 5th grade children relied mainly on the textbook and answered as briefly as possible (as it was demanded in lessons). If they were not sure they answered very quickly: "I don't know". Only after several questions would it turn out that they knew but were afraid to make a mistake. Others related everything they could remember. For example:

Interviewer	Tell me, why day and night change?
Ann	Because the Earth rotates around its axis and around the Sun.
Interviewer	Oh yes. But can you explain the variation in more detail. What movement exactly causes the variation?
Ann	The Earth rotates around its axis and then one side of the Earth is toward the Sun and there is day. But the Earth also revolves around the Sun.
Interviewer	Yes, that's right. But are both movements necessary for us to have day and night?
Ann	No, the Earth's revolution around the Sun causes the seasonal changes.

There were more pauses and hesitations in the 9th grade. Students did not remember the book's text any more, they had to try to call from memory, base on their everyday experiences, make conclusions. For example (an interview with the same student):

Interviewer	Tell me, why day and night variate?
Ann	Mm... because the Sun goes around the Earth.
Interviewer	Oh I see but try to explain it in detail.
Ann	The Sun goes... no... the Earth goes around the Sun I think...how was it?
Interviewer	You think that the Earth turns around the Sun but try to explain how day and night change.
Ann	The Earth goes around... no I think it was the Sun that turned around the Earth and... I don't remember any more/ we learnt it a long time ago.

It is seen that the student still tries to remember what was taught in lessons 4 years ago. As she could not remember, everyday knowledge (the Sun revolves) becomes dominant.

Interestingly, only the 9th grade students hesitated when deciding which speech genre to use — either scientific or everyday — when responding to the interviewer (Michaels & Bruce, 1989; Wertsch, 1991). 5th grade students gave causal physical explanations (as well as they knew them) at the beginning of the interview. Ten 9th graders started with everyday, personal explanations (e.g., "Day and night change because we must rest", "Seasons change because it is interesting") and only after several hints from the interviewer did they proceed with causal explanations[4].

Summary and discussion

In the investigation, the long-term impact of teaching on children's definitions of astronomy concepts (equator, axis, orbit) and explanations of phenomena (day/night variation and seasonal changes) was studied. Students remembered the definitions and explanations quite well 2 months after studying them. They did not seek solutions from personal experience but referred to books' words quite exactly. On the whole, they had acquired terms and theories on the level it was demanded in school. The picture had changed 4 years after the "learning" experiment. Students had forgotten the scientific definitions, explanations and facts and used their everyday knowledge. Their answers were similar to younger children's explanations found in other empirical studies.

The most dramatic differences were found between explanations. Our 9th graders gave less scientific answers than 5th graders. Half of them even started with personal answers but could transfer to causal (but not scientifically correct) answers (i.e., to the speech genre of "official science") afterwards. But these were mainly synthetic answers that tried to combine everyday knowledge (the Sun moves) with causal reasoning (to find physical reasons for changes).

The results of our longitudinal study differ from that which has been found before by other researchers. Both Sadler (1987) and Michaels and Bruce (1989) found that students did not know scientific definitions and explanations even shortly after learning them in school. Our students had memorized the information quite exactly (5th grade). We also showed that they had been trained during lessons quite well. The teacher repeated the definitions and explanations many times, students had to answer shortly, with the book's and teacher's words.

Vosniadou and Brewer (1994) found that older students used more scientific and younger ones more initial and synthetic models. They have not studied the impact of school education on the formation of students' models but argue only for the developmental changes: "...the majority of first-grade children enter school having formed an initial model of the day/night cycle. During elementary school years they appear to replace the initial model with a synthetic model. By the end of their elementary school years, some children have replaced their synthetic model with scientific model" (pp. 170–171).

Our results may be explained by taking into account the teaching methods used in the school. One reason for good factual answers in the 5th grade and their later decline seems to be in a very traditional and teacher-centered teaching.

[4] These causal explanations even if given after everyday explanations are given in Table 1 and were used in analyses.

The movements of the Earth were taught in school and repeated many times during lessons. The teacher relied heavily on the textbook. She talked about the Sun as a center of the Planetary System, drew a schema on the blackboard. Students memorized the new information (definitions, explanations) but did not discuss it. It was not "talking science" but "memorizing science". There was no need to use the information in a scientific way (e.g., for solving problems, discussing phenomena) (see Tulviste, 1991). No questions to which the answer was not written in the book (e.g., generative questions, see Vosniadou 1994) were asked in the lessons.

At the same time, the teaching did not rely on students' everyday knowledge. The teacher did not discuss why we see the rising and setting Sun but talked only about the rotation (and revolution) of the Earth. We cannot deduce a heliocentric model only on the bases of our sensorial perception. A deeper explanation of unobservable phenomena is necessary here (see Albanese, Danhoni Neves & Vicentini, In Press). As the teaching did not encourage the integration of everyday and school knowledge, students forgot the book's explanations and turned back to their everyday knowledge several years after learning.

The results also show that with factual questions it is impossible to obtain a deeper insight into students' mental models and to investigate whether they had really understood the phenomena. The fact is that the teachers determine the students' understanding with these questions and just after teaching the topic.

The study showed that the 5th graders' scientifically correct answers did not mean that they had understood the phenomena. "Good" answers were the repetitions of the books' words which students could give without fully understanding them. The impact of teaching where the stress is on memorizing may seem great shortly after learning. But such teaching is not effective in the longer perspective.

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Table 1

Textbook's and students' definitions and explanations					
Term/ phenome- non	Answer	Type		Nr of answers 5th grade	9th grade
Axis	**Imaginary line that goes through the center of the Earth. The Earth rotates around its axis**	Abstract	Correct	5	2
	The line through the Earth	Abstract	Correct	1	0
	Imaginary around which the Earth rotates	Descriptive	Correct	6	5
	Imaginary that goes through the Earth	Descriptive	Correct	1	2
	That which goes through the Earth	Descriptive	Correct	1	2
	The Earth rotates around it	Descriptive	Correct	1	1
	In the Earth	Other	Others	1	2
	Tilted a little	Other	Others	4	0
	I don't know	Other	Others	0	6
Orbit	**The way along which the Earth revolves around the Sun**	Abstract	Correct	7	5
	The path of the Earth	Abstract	Correct	2	2
	Along which the Earth revolves around the Sun	Descriptive	Correct	2	1
	Way along which the Earth rotates around its axis	Other	Others	6	2
	The path of the Sun	Other	Others	0	3
	I don't know	Other	Others	3	7
Equator	**Imaginary line around the Earth that is on the same distance from Northern and Southern Poles**	Abstract	Correct	11	5
	Line around the Earth	Abstract	Correct	1	2
	That is around the Earth & divides it into halves	Descriptive	Correct	5	4
	The pole of the Earth	Other	Others	1	0
	The axis of the Earth	Other	Others	2	0
	The center of the Earth	Other	Others	0	2
	I don't know	Other	Others	0	7
Day/night variation	**The Earth rotates around its axis, sometimes one side of the Earth is towards the Sund, other times another side, day is on the side of the Earth where there is the Sun**	Exact	Earth-	13	4
	The Earth rotates around its axis and around the Sun some-times one side is toward the Sun, other times another side)	All	Earth-	2	4
	The Earth revolves around the Sun, sometimes one side is toward the Sun, other times another side	Mixed	Earth-	3	4
	The Sun revolves around the Earth, sometimes one side is toward the Sun, other times another side	Sun	Others	1	7
	The Sun shines in daytime and the Moon at night	Descriptive	Others	1	0
	It is dark at night	Descriptive	Others	0	1
Seasonal changes	**The Sun warms Southern and Northern Hemispheres differently because the Earth's axis is tilted and the Earth revolves around the Sun**	Exact	Earth-	10	4
	The Earth rotates around its axis and around the Sun, the Sun lightens one side more than another	All	Earth-	2	4
	The eErth rotates around its axis, the Sun lightens one side more than another	Mixed	Earth-	5	3
	The Sun revolves around the Earth, it moves differently in summer and in winter	Sun	Others	0	7
	The Sun doesn't shine so much in winter	Descriptive	Others	1	0
	It is cold in winter	Descriptive	Others	2	2

Legend

The answers written in bold print are those given in the textbook and demanded in lessons.

Table 2

The content and structure of lessons: topics studied and activities occured

Lesson/topic	Total	Checking home learnt material	Introducing the new material	Activity Reading the book	Checking the new material	Solving the problems
1. Celestial bodies	100	0	27	23	23	27
2. Planetary system	100	25	0	14	30	31
3. Day & Night variation	100	20	25	15	21	19
4. Seasonal changes I	100	23	32	18	27	0
5. Seasonal changes II	100	58	0	0	0	42
6. The Moon. Outer space	100	37	0	5	18	40
7. Repeating the previous and introducing the new material	100	28	27	15	21	9
Average	100	27	16	13	20	24

IV

Kikas, E. The impact of teaching on students' explanations of astronomical phenomena. *Language and Communication* (in press)

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THE IMPACT OF TEACHING ON STUDENTS' EXPLANATIONS OF ASTRONOMICAL PHENOMENA

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The influence of school education on children's explanations of astronomical phenomena (of day/night variation and seasonal changes) was studied. First, we analyzed how the topic was taught in textbooks. Second, 252 3rd, 5th, 7th and 9th grade students were questioned in a written form. Answers were categorized into "school-based" (explaining the phenomena by the movements of the Earth) and everyday (descriptive and "Sun-based") explanations. The strong impact of teaching on students' explanations 6 months after learning the topic in the 5th grade was determined. But as students only memorized the school knowledge, this impact did not last long. Students forgot scientific explanations — 7th and 9th graders gave more everyday explanations than 5th graders. At the same time, new themes related with new topics learnt at school emerged in the answers.

Introduction

Children have integrated knowledge of physical phenomena which usually differs from scientific explanations. It has been shown that this knowledge is compromised into naive theories (or mental models) which are derived from children's everyday experience (Carey, 1985; Neisser, 1987; Keil, 1989; Vosniadou, 1992).

Scientific explanations are learnt in school. Differently from everyday experiences, verbal descriptions, explanations and logical argumentation are of great importance here as much talk is done about out-of-empiric phenomena (Vygotsky, 1962; Tulviste, 1991). Some authors stress that students learn a new way of speaking at school. It is called either talking in a language of "official science" (Wertsch, 1991), in "literate register" (Snow 1990) or simply "talking science" (Lemke, 1990).

Great problems with science education have been documented over decades (see an overview in different subjects in Glynn, Yeany & Britton, 1991; a bibliography in Pfundt & Duit, 1994). Actually, young children's mental models are very difficult to change at school especially if they radically differ from scientific explanations and therefore one faces the need for inevitable knowledge restructuring (White, 1983; Driver, Guesne & Tiberhgien, 1985; Vosniadou, 1992; Chi, Slotta & Leeuw, 1994; Tiberghien, 1994). It has been shown that children learn from school mainly the knowledge that does not contradict their everyday experiences. Students also make compromises, forming synthetic models (also called misconceptions) which are the attempts to integrate scientific and everyday information (Vosniadou, 1992). Ideally, synthetic models are replaced with scientific ones at last.

At least to some extent, the difficulties occur due to traditional teaching methods. It has been shown that traditional textbooks and teaching give new information (facts, definitions, explanations) that does not take into account students' previous (naive) conceptions (Michaels & Bruce, 1989; Renner, Abraham & Grzybowsky, 1990; Pizzini, Shepardson & Abell, 1992; Driscoll *et al.*, 1994). Also, students are only passive recipients not active knowledge builders in the traditional classrooms (Glynn, Yeany & Britton, 1991). As a result, school knowledge remains quite separate from everyday one.

Astronomy is one of the fields where everyday models differ quite substantially from scientific explanation of phenomena. It has been shown by several studies that children's astronomical models are consistent and difficult to change. The explanations of the reasons for day/night variation and seasonal changes have also been studied time and again (Sadler, 1987; Michaels & Bruce, 1989; Baxter, 1989; Vosniadou & Brewer, 1994).

Vosniadou and Brewer found that 38 students out of 60 (1st, 3rd and 5th graders, 6–11 years old) had coherent day/night variation explanations and used their models consistently. They found that 1st graders generally had initial models. These models were derived and consistent with the observations of everyday life (the Sun is occluded by clouds or darkness; day is replaced by night; the Sun goes out at night; the Sun goes behind hills). Students replaced their initial astronomical models with synthetic ones (the Earth goes around the Sun; the Moon blocks the Sun; the Sun moves in the space, the Sun and Moon move; the Earth rotates up/down; the Earth rotates and revolves) during elementary school years (3rd and 5th grades). Baxter (1989; 20 9–16 year-old) also found that younger children told more that the Sun revolved around the Earth and older students that the Earth spinned.

Ideally, synthetic models are replaced with scientific ones (e.g., day/night variation is explained with the fact that the Earth spins) at school. But it has been shown that even 15–16 year old students have synthetic models (Baxter, 1989). Sadler (1987; 25 9th graders) found that the students who were completing scientific course in astronomy did not give more correct answers than those who were not. They only used more scientific terms (orbit, tilt etc.).

Michaels and Bruce (1989) analyzed how the topic of seasonal changes was taught in the 4th grade textbook. They found that several scientific terms were taught but the actual scientific explanation was so reduced and misleading that it was impossible to understand it. They showed that nobody (out of 20 students) learned the causal (scientific) explanation in lessons. They found that several students gave personal explanations (the seasons change because flowers need a rest; we can skate in winter).

We replicated the study of Michaels and Bruce in Estonia (5th grade, 20 students). Although the topic was taught in the same way in Estonian textbook, the students' explanations 2 months after learning the topic at school were very different. Estonian students had memorized the explanations quite well and answered to the interviewer with book's words (Kikas 1992, 1994).

But the impact of learning did not last long. We interviewed the same students 4 years after learning the topic at school (9th grade) (unpublished data). It turned out that they had forgotten the book's explanations: the majority of them had returned to synthetic and even initial explanations. As there were only 20 subjects (from one class) in our longitudinal study, we carried out a cross-age study with more students.

The present investigation was aimed to determine the influence of school education on children's explanations of astronomical phenomena (day/night variation and seasonal changes). We could show the strong impact of teaching on students' explanations shortly after learning the topics at school. But as students only memorized the school knowledge without integrating into their everyday knowledge they returned to everyday explanations afterwards.

Method

Subjects

Our investigation was conducted in 4 usual Estonian secondary schools in Tartu (the second largest town in Estonia, population approximately 120 000, 16 schools). At all the schools science was taught according to the same program. The subjects for the study were 252 schoolchildren: 46 third graders (age 9–10, 30 girls, 16 boys); 75 fifth graders, (age 11–12, 31 girls, 44 boys); 52 seventh graders (age 13–14, 32 girls, 20 boys) 79 ninth graders (age 15–17, 44 girls, 35 boys).

Procedure

1. Preliminary analyses of textbooks. A special attention was paid to the ways day/night variation and seasonal changes were explained in textbooks.

2. Testing children. The children were tested in a written form with the whole class. The following questions were asked:

- Why do night and day change?
- Why do seasons change?

The answers to the questions were analyzed.

Results

Textbook discourse

The themes "Day and night variation" and "Seasonal changes" are studied for the first time in the 5th grade in science lessons. Estonian schools have a science textbook (Nilson & Tiits, 1988) and a workbook (Nilson & Tiits, 1989). Text contains of five interrelated subtopics and a summary:

1. Celestial Bodies (2 pages of text with 1 figure and 12 questions; 7 new terms with definitions in the textbook, 4 exercises in the workbook).
2. Planetary System (3 pages, 2 figures, 8 questions, 4 new terms, 3 exercises).
3. Day and Night Variation (3.5 pages, 3 figures, 8 questions, 2 new terms, 6 exercises).
4. Seasonal Changes (3.5 pages, 3 figures, 7 questions, 2 new terms, 7 exercises).
5. The Moon. Exploration of the Outer Space (3 pages, 1 figure, 9 questions, 4 new terms, 5 exercises).
6. Summary (1.5 pages, 24 questions on the whole topic).

The emphasis is on definitions of terms and long descriptions of phenomena. The parts that are stressed are printed in bold and separately. The following explanations of day/night and seasonal changes are printed in bold:

"*Day and night change because the Earth rotates around it's axis, sometimes one side of the Earth is towards the Sun, another times another side, day is on this side of the Earth where there is the Sun*";

"*Seasons change because the Sun warms Southern and Northern Hemispheres differently because the Earth's axis is tilted and the Earth revolves around the Sun*".

The book's explanations take into account neither children's naive theories nor stress the critical knowledge necessary for understanding scientific explanations. The answers to the questions in workbook can be found from directly from the text.

Seasonal changes are implicitly treated in the 7th grade during learning the topic "Climate" (subtopics "The Factors that Influence Climate" and "Climate Zones"). There is no general explanation of why seasons change in the textbook (Jõgi *et al.*, 1992). But there are long descriptions of different climate zones (equatorial, temperate zone etc.), their geographical position and differences in temperature.

Children's knowledge

Proceeding from the empirical data, we divided the explanations of the reasons for day/night variation and seasonal changes into four (sub)categories which were grouped into two major categories.

1. **"School-based"** answers give physical reasons (connected with the movements of the Earth) that are learnt at school. Here, **"exact"** answers contain more or less "exact" textbook explanation (see before). In **"Mixed"** answers student tells either all s/he remembers (explaining reasons for either day/night variation or seasonal changes by the fact that the Earth revolves around the axis and around the Sun) or mixes up reasons for day/night and seasonal changes.

2. **"Everyday"** answers. Here, **"Sun"** answers give the reason for changes in the Sun rotating around the Earth. It is also a causal explanation but actually wrong: it is taught at school that not the Sun but the Earth revolves around[1]. **"Descriptive" answers** do not give any causal (physical) reason for the change but either describe what can be seen or felt or give personal explanations.

As compared to Vosniadou's and Brewer's classification schema (1994), "exact" explanations can be identified to scientific, "mixed" and "Sun" answers to synthetic and descriptive answers to initial explanations. As our interest was mainly on the impact of teaching on explanations we preferred to use the categories "school-based" and "everyday" (and corresponding subcategories "exact", "mixed", "Sun" and "descriptive").

Quantitative Changes

The number and percentage of students' answers in each subcategory and category in different grades are shown in Table 1 (for day/night variation) and in Table 2 (for seasonal changes).

[1] At least it is wrong in school context. According both to Galilean and Einsteinian relativity theory, it is all the same either to tell that the Earth revolves around the Sun or the Sun revolves around the Earth. But there is a difference between the easiness and convenience in describing these revolutions. For sure, the Sun's revolution alone does not cause day/night variation.

Table 1

The distribution of explanations of day/night variation in different grades (in numbers and percentage)

Grade	Number and % of answers											
	Descriptive		Sun		**Others**		Mixed		Exact		**School-based**	
	Nr.	%	Nr.	%	**Nr.**	**%**	Nr.	%	Nr.	%	**Nr.**	**%**
3rd	30	65	5	11	**35**	**76**	5	11	6	13	**11**	**24**
5th	15	20	1	1	**16**	**21**	20	27	39	52	**59**	**79**
7th	18	35	4	8	**22**	**43**	11	21	19	37	**30**	**58**
9th	19	24	11	14	**30**	**38**	19	24	30	38	**49**	**62**

Table 2

The distribution of explanations of seasonal changes in different grades (in numbers and percentage)

Grade	Number and % of answers											
	Descriptive		Sun		**Others**		Mixed		Exact		**School-based**	
	Nr.	%	Nr.	%	**Nr.**	**%**	Nr.	%	Nr.	%	**Nr.**	**%**
3rd	42	91	1	2	**43**	**93**	2	4	1	2	**3**	**6**
5th	18	24	1	1	**19**	**25**	12	16	44	59	**36**	**75**
7th	21	40	4	8	**25**	**48**	11	21	16	31	**27**	**52**
9th	17	22	11	14	**28**	**36**	14	18	37	47	**51**	**65**

It is seen from the tables that 3rd graders gave mainly descriptive answers (65% of answers for day/night variation and 91% for seasonal changes). Still, some students explained phenomena with the movements of the Earth (gave "school-based" answers).

The majority of 5th graders' answers were "school-based". Even more, they were mainly "exact" (52% for day/night variation and 59% for seasonal changes). The difference between "school-based" answers in the 3rd and 5th grades was statistically highly significant; $\chi2(1)=35.06$, $p=0.0000$ (for day/night variation) and $\chi2(1)=52.99$, $p=0.0000$ (for seasonal changes).

There were less "school-based" answers in the 7th (58% and 52%) and 9th (62% and 65%) grades than in the 5th grade. The difference was statistically significant between the 5th and the 7th grades for both explanations ($\chi2(1)= 6.44$, $p=0.01$ for day/night variation; $\chi2(1)=7.01$, $p=0.008$ for seasonal changes) and for explanation of day/night variation between the 5th and 9th grades ($\chi2(1)=5.08$, $p=0.024$) but nonsignificant for seasonal changes ($\chi2(1)=1.85$, $p=0.173$).

There was a high consistency in explanations of day/night and seasonal changes in all grades; Spearman's rank correlation coefficient $R=0.806$, $p=0.000$. So, students tend to explain both phenomena relatedly, in the same manner (compare Vosniadou & Brewer, 1994).

Except in the 5th grade, boys gave more "school-based" answers than the girls. The difference was extremely high and statistically significant in the 9th grade, $\chi2(1)=24.27$; $p=0.0000$ (for seasonal changes) and $\chi2(1)=18.8$; $p=0.000$ (for day/night variation). 9th grade boys gave mainly "school-based" answers (89% for day/night variation and 94% for seasonal changes). Only 41% of girls gave "school-based" answers (for both phenomena), all the "Sun"-explanations were also given by girls. There were no statistically significant differences between the boys' and girls' marks in mathematics, science and language.

The Content of the Answers

The majority of 3rd grade answers were either personal explanations (e.g., "Day and night change because we need to rest") or descriptions of different seasons and day/night (e.g., "The Sun shines at daytime and the Moon and stars at night").

The majority of 5th grade explanations were like those written in the textbook. Explanations were quite similar to each other, more or less in book's words. Children's answers differed in how well they had remembered the differences between the Earth's rotation around it's axis and around the Sun: some children mixed up the explanations for day/night and the seasonal changes, some couldn't distinguish between "exact" reasons of changes and, therefore, told everything they remembered.

There was more variety in 7th and 9th graders' answers. The 5th grade science textbook was not the main source of the knowledge any more. 14% of students wrote that the Sun revolved around the Earth. Descriptions were longer and of different aspects of changes, some of them were very poetic. For example: "A morning starts with sunrise. The higher the Sun the more beautiful becomes the day. A night starts with sunset which is very nice to look at. The Moon comes out. There are different types of Moons."

The impact of teaching was seen in new themes driven from lately studied topics. 31% of 7th graders (5% of 9th graders) referred to our geographical position, climate zones, equator while explaining the reasons of seasonal changes. For example: "Seasons change because we do not live near equator"; "Seasons change because we live in a temperate zone which is not very close to the Sun". These were themes that had been studied in the 7th grade (4 months before questioning students).

Summary and discussion

In our cross-age investigation the impact of learning on children's explanations of day/night variation and seasonal changes was studied. We showed that students memorized the knowledge taught in lessons quite exactly but did not integrate it into their everyday knowledge and forgot it soon. At the same time, new themes, learned in older grades, emerged in the answers.

3rd grade students had mainly naïve "everyday" explanations for both phenomena. Students gave "school-based" explanations in the 5th grade, 6 months after learning the topic at school. They used book's words quite exactly. But as the students did not integrate their everyday and school knowledge, they forgot the latter soon and drop down to previous explanations. Many 7th and 9th grade students had forgotten book's explanations and had to use their everyday knowledge. Their answers were more "childish" than in the 5th grade. The impact of teaching was seen in new themes emerged from the recently studied topics (climate zones, geographical position in 7th grade).

The finding that boys gave more "school-based" answers than girls needs further clarification especially in the context that boys were not better students at school.

The results of our study differ from what has been found before. Both Sadler (1987) and Michaels and Bruce (1989) found that students had not acquired scientific explanations even shortly after learning them at school. Our students had memorized the information quite exactly (5th grade).

Vosniadou and Brewer (1994) found that older students had more scientific, younger ones more initial and synthetic models. Our 7th and 9th graders gave less "exact" answers than 5th graders. There were more synthetic answers that tried to combine everyday knowledge (the Sun moves) with causal reasoning (to find physical reasons for changes). These results can be explained only by taking into account the impact of teaching at school on the formation of children's explanations.

One reason for good answers in the 5th grade and the later decline seems to be in a very traditional and teacher-centered teaching. We have shown before (Kikas, 1994) that students were trained during lessons quite much. Students memorized the new information but did not discuss about it. There was no need to use the information in a scientific way (e.g., for solving problems, compare Tulviste, 1991). It seems that the impact of teaching where the stress is on memorizing, may be great shortly after learning but not in the longer perspective.

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V

Kikas, E. Students' understanding of astronomical phenomena. Development of verbal explanations and drawings. (submitted)

STUDENTS' UNDERSTANDING OF ASTRONOMICAL PHENOMENA: DEVELOPMENT OF VERBAL EXPLANATIONS AND DRAWINGS

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A study of the development of children's ability to explain and illustrate astronomical phenomena (day/night variations and seasonal changes), and the influences of education on it, was carried out. An initial analysis was conducted of the way the topics were covered in the textbooks. Subsequently, 252 3rd, 5th, 7th and 9th grade students were questioned in a written form in order to establish their ability to explain and illustrate the phenomena. Explanations and drawings were analyzed both separately and in relation to one another. The results indicated different impact of teaching on students' explanations and illustrations. 6 months after learning the topic in the 5th grade, students gave mainly exact textbook's explanations but aggregate illustrations. As their verbal acquisition of knowledge was quite illusory, students returned to everyday — aggregate and descriptive — explanations in older grades. Our results show that the teaching method where stress is on memorizing gives outwardly good results shortly after learning. But as the integration of everyday and school knowledge is not encouraged, a tendency to turn back to everyday explanations may be followed. The results raise also the question of assessing students' understanding of knowledge in general.

Introduction

The investigation was aimed to study the development of children's ability to explain and illustrate astronomical phenomena (day/night variations and seasonal changes) and the influences of education on the development. Proceeding from Sociocultural approach, textbook discourse, children's explanations, and drawings were studied and analyzed.

Development of concepts

Children's everyday experience provides a lot of information to develop their understanding of the world. Besides child's own observation, development of concepts is also influenced by culture, society and parents. While Piaget (1926, 1932) finds the child's own exploration of the world the main reason for conceptual development, then Vygotsky (1994a) stresses the sociocultural origin of development instead.

Vygotsky (1994b, 1994c) distinguishes between scientific and everyday (or spontaneous) concepts. Everyday concepts are mastered by being in direct contact with their references (the objects to which the word for the concept refers) or observing the corresponding phenomena. These concepts develop from concrete instances to general abstractions. Child's internal activity is important for the development of everyday concepts. Vygotsky assumed that everyday concepts do not fall into system.

Vygotsky associates the impact of school education on the child's thinking processes with the development of new kind of concepts, namely, scientific ones. It is important to stress that he does not regard scientific concepts simply as those related to natural or exact sciences but rather identifies them with the ones learnt in school. It is characteristic to scientific concepts that 1) they belong to a special conceptual system; 2) they enter into "supraempirical", experience-external connections, and 3) the thinker reflects on them (Kikas, 1991). Vygotsky stresses that although scientific concepts are learnt verbally, they are not acquired in ready-made form. At the same time, they develop differently from everyday concepts.

The latter peculiarities of scientific concepts come from the characteristics of school education. Knowledge taught in school (e.g., in science lessons) is based on a contemporary scientific view. Although derived from observational data, scientific explanations are theory-based, enabling (even demanding) experience-external connections inbetween concepts (Kuhn, 1962; Tulviste, 1991; Carey & Smith, 1993; Albanese *et al.*, in press). Talking about nowadays scientific explanations frequently means a talk about unseen phenomena and relations. Therefore, verbal descriptions, explanations, and logical inferences are of great importance in this learning process (Vygotsky, 1994c; Tulviste, 1991). Frequently, illustrations (models, schemes) are used to facilitate the understanding of phenomena, and concretize verbal explanations. Illustrative tools are not a direct diminished copy of the reality but the ones for symbolizing the phenomena and communicating implicit information as well (i.e., mediational means or signs, see Vygotsky, 1982). Vygotsky (1994c) talks about the developmental advantage of scientific concepts compared with everyday ones, just because they belong to a special system, and because they are co-constructed by a student, together with a teacher.

The difficulty of child's use of scientific concepts is in their abstractness and detachment from reality. In the course of teaching and learning, scientific concepts influence and interact with everyday ones and, therefore, should be filled with concrete experience. Vygotsky writes that the development of concepts is a time-consuming and complicated thinking process presupposing the development of several intellectual functions (e.g., deliberate attention, abstraction). When a child hears a new word (e.g., in the form of definition), the development is starting not ending. Vygotsky warns against verbalisms in teaching when children do not acquire concepts but words, relying mainly on their memory and not on thinking, therefore not being able to use their knowledge.

Recent studies have shown that children's everyday concepts are embedded in larger theoretical structures. These are called naïve theories (or mental models) and they are different from nowadays scientific theories (Carey, 1985; Murphy & Medin, 1985; Neisser, 1987; Keil, 1989; Vosniadou, 1992). But it has also been shown that although children's knowledge is to some extent integrated they are not able to reflect on it. In fact, it appears that young children's everyday models are very difficult to change by teaching especially if they essentially differ from scientific explanations, and therefore, radical knowledge restructuring is inevitable (White, 1983; Driver, Guesne & Tiberghien, 1985; Neisser, 1987; Vosniadou, 1992; Chi, Slotta & Leeuw, 1994; Vosniadou & Brewer, 1994; Glynn & Duit, 1995). Students learn from school the knowledge that does not contradict their everyday experiences. They also form synthetic models (also called misconceptions) which are compromises between everyday beliefs and school knowledge (Vosniadou, 1992). Sometimes they acquire scientific concepts mainly verbally (mere verbalisms according to Vygotsky), their later integration with everyday models not taking place (school and everyday concepts remain separate).

Children's naïve theories of astronomy and education

Children get information about astronomical phenomena by observation: they see that the Earth is flat, the Sun rises in the morning and sets in the evening (i.e., the Sun is moving in the sky), that the Sun is lower in the sky in winter and higher in summer. Children construct their understanding actively from what they see (everyday concepts). Even more, the everyday expressions commonly used give the countenance to the acquisition of these concepts: it is said that the Sun rises and even (at least in Estonia) that it goes to sleep at night.

It is not possible to derive nowadays heliocentric astronomical model basing only on everyday perceptual information. In fact theories in astronomy as a scientific discipline have undergone a radical restructuring in the course of the historical development. It has been shown that there is a noticeable similarity between children's mental models of astronomy and the explanations found in history: young children's mental models are similar to theories used in ancient and medieval times (Vosniadou, 1992; Albanese *et al.*, in press).

Nowadays heliocentric theory (the Sun as the center of Planetary System, the Earth rotating and revolving) (scientific concept) is taught in school by verbal explanations (given in textbooks and by teachers). As with other difficult phenomena which we cannot observe directly (we neither see nor feel the Earth's movements), models and schemes are used to clarify the explanations.

It has been shown by several studies that children's naive astronomical models are consistent and difficult to change (Sadler, 1987; Michaels & Bruce, 1989; Baxter, 1989; 1995; Vosniadou, 1992; Vosniadou & Brewer, 1992; Vosniadou & Brewer, 1994; Arnold, Sarge & Worrall, 1995).

Vosniadou and Brewer found that 1st graders' (initial) models were derived from the observations ("the Sun is occluded by clouds or darkness"; "day is replaced by night"; "the Sun goes out at night"; "the Sun goes behind hills"). Students replaced their initial astronomical models by synthetic ones ("the Earth goes around the Sun"; "the Moon blocks the Sun"; "the Sun moves in the space", "the Sun and Moon move"; "the Earth rotates up/down"; "the Earth rotates and revolves") during elementary school years (3rd and 5th grades). Ideally, synthetic models are replaced by scientific ones (i.e., day/night variation is explained by the fact that the Earth spins) in school. But it has been shown that even 15–16 year old students have synthetic models (Baxter, 1989). Sadler (1987) found that 9th grade students who were completing scientific course in astronomy did not give more correct answers than those who were not. They only used more scientific terms (e.g., orbit, tilt), i.e., had acquired words, not their exact meaning.

Michaels and Bruce (1989) showed that nobody out of 20 4th graders learned the causal (scientific) explanation of seasonal changes in lessons. The majority of students still had a "distance theory" ("it is colder in winter because the Sun is further from the Earth") but several students gave personal explanations ("the seasons change because flowers need a rest"; "we can skate in winter") as well. They also analyzed how the topic of seasonal changes was taught in the textbook and found that several scientific terms were taught but the actual scientific explanation was so reduced and misleading that it was impossible to understand it.

We have shown in a longitudinal study with 20 students (unpublished data) that students remembered the explanations of seasonal and day/night changes 2 months after learning the topic in school (5^{th} grade) very well. Their explanations were quite similar to textbook's ones. But the picture had changed 4 years later (9^{th} grade, the same students). Students had forgotten the book's explanation and the majority of them had returned to synthetic ("the Sun revolves around the Earth") and even personal ("we have night because we must rest") explanations.

Besides questions, illustrations have also been used to study students' astronomical models (e.g., Vosniadou & Brewer, 1992, 1994; Arnold, Sarge & Worrall, 1995; Baxter, 1995). Drawings are specially helpful to understand synthetic models which actually are the compromises between initial (what is seen) and scientific (what is talked about in school) concepts.

At least to some extent, the difficulties in conceptual development occur due to traditional teaching methods. It has been shown that traditional textbooks and teaching give new information (facts, definitions, explanations) that does not take into account students' previous (naive) conceptions (Michaels & Bruce, 1989; Renner, Abraham & Grzybowsky, 1990; Pizzini, Shepardson & Abell, 1992; Driscoll, Moallem, Dick & Kirby, 1994; Stinner, 1995). This new knowledge remains quite far and abstract for a child. In addition, textbooks' illustrations are sometimes quite misleading. Michaels and Bruce (1989) showed that the scheme illustrating seasonal changes gave countenance for "distance theory" as the orbit of the Earth was drawn as an ellipse. Students' ease or difficulty in using models and schemes is influenced by their knowledge of what models are intended to communicate. It has been shown that most of the middle school students think models to be little copies of real-world objects (Grosslight, Unger, Jay, & Smith, 1991). If students do not understand what models are intended to be represented, they apparently fail to comprehend the representational systems behind them.

Also, students are only passive recipients not active knowledge builders in the traditional classrooms where the instructional mode of lecture, question and answer is widely used. Teachers deliver facts and explanations and the students' task is to memorize them in order to know the answer to the evaluative questions (Glynn & Duit, 1995; Glynn, Yeany & Britton, 1991). Vygotsky was against these methods: "Direct teaching of concepts is impossible and fruitless. A teacher who tries to do this usually accomplishes nothing but empty verbalism, a parrotlike repetition of words by a child, simulating a knowledge of the corresponding concepts but actually covering up a vacuum" (1994c, p. 150).

Method

Subjects

Our investigation was conducted in 4 Estonian secondary schools of Tartu (the second largest town in Estonia, population approximately 120 000, 16 schools). In all four schools science was taught according to the same program (the textbooks were the same as well). The subjects for the study were 252 schoolchildren: 46 third graders (age 9–10, 30 girls, 16 boys); 75 fifth graders, (age 11–12, 31 girls, 44 boys); 52 seventh graders (age 13–14, 32 girls, 20 boys); 79 ninth graders (age 15–17, 44 girls, 35 boys).

Procedure

1. **Analyzing textbook discourse**. We looked through all the textbooks that are used in Estonian schools in science lessons till 9th grade. The same textbooks have been used in the schools for decades. It means that all 5th, 7th, and 9th graders have used the same book in learning the topics. We studied the text and illustrations explaining day/night variation and seasonal changes.

2. **Testing children.** The children were tested in a written form with the whole class being present. The following questions were asked:

- Why do night and day change? Illustrate your answer.
- Why do seasons change? Illustrate your answer.

3. **Categorizing answers.** The answers to the questions and their illustrations were analyzed both separately and in relation to each other. Proceeding from the empirical data, explanations and illustrations were divided into three categories. Examples of answers in each category are given in Table 1 and Figures 1–2.

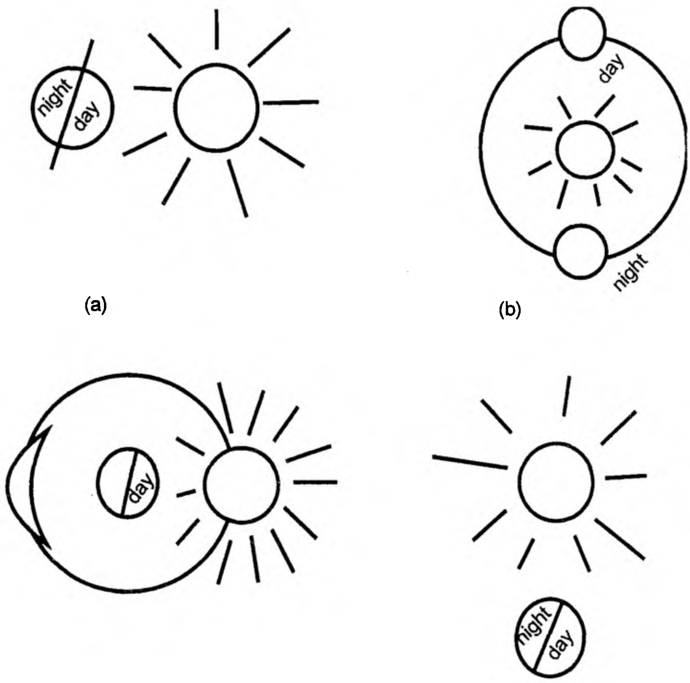
Table 1. Examples of explanations in each category

Category	Explanation
	Day/night variation
Exact	1. Day and night change because the Earth rotates around its axis, sometimes one side of the Earth is toward the Sun, other times another side, day is on this side where there is the Sun.
Synthetic	1. Day and night change because the Earth revolves around the Sun, sometimes … (the same as before)
	2. Day and night change because the Earth rotates around its axis and around the Sun, sometimes…
	3. Day and night change because the Sun revolves around the Earth, sometimes …
Descriptive	1. Day and night change because we need to rest at night.
	2. Day and night change because the Sun shines in daytime and the Moon at night.
	3. A morning begins with sunrise. The higher the Sun the more beautiful becomes a day. A night begins with sunset which is very beautiful to look at. The Moon comes out. There are different types of moons.
	Seasonal changes
Exact	1. Seasons change because the Earth revolves around the Sun and the Sun warms the Southern and Northern parts of the Earth differently.
Synthetic	1. Seasons change because the Earth rotates around its axis.
	2. Seasons change because the Sun revolves around the Earth.
Descriptive	1. Seasons change because it is cold in winter and warm in summer.
	2. Seasons change because it is interesting to ski in winter and swim in summer
	3. Seasons change because we live far away from the equator.
	4. The Sun is hot in summer. It rains a lot in autumn and the Sun is very cold in winter. It is a little bit warmer in spring.
	5. Seasons change because we live in a temperate zone which is not very close to the Sun.

I **Exact** answers contain more or less exact textbook explanation. Students explain the phenomena correctly by the movements of the Earth. The illustrations are also similar to those in the textbook (Figures 1a, 2a–b). The orbit of the Earth could be either ellipse an or a circle (Figures 2a–b).

Figure 1

Examples of students' illustrations of day/night variation

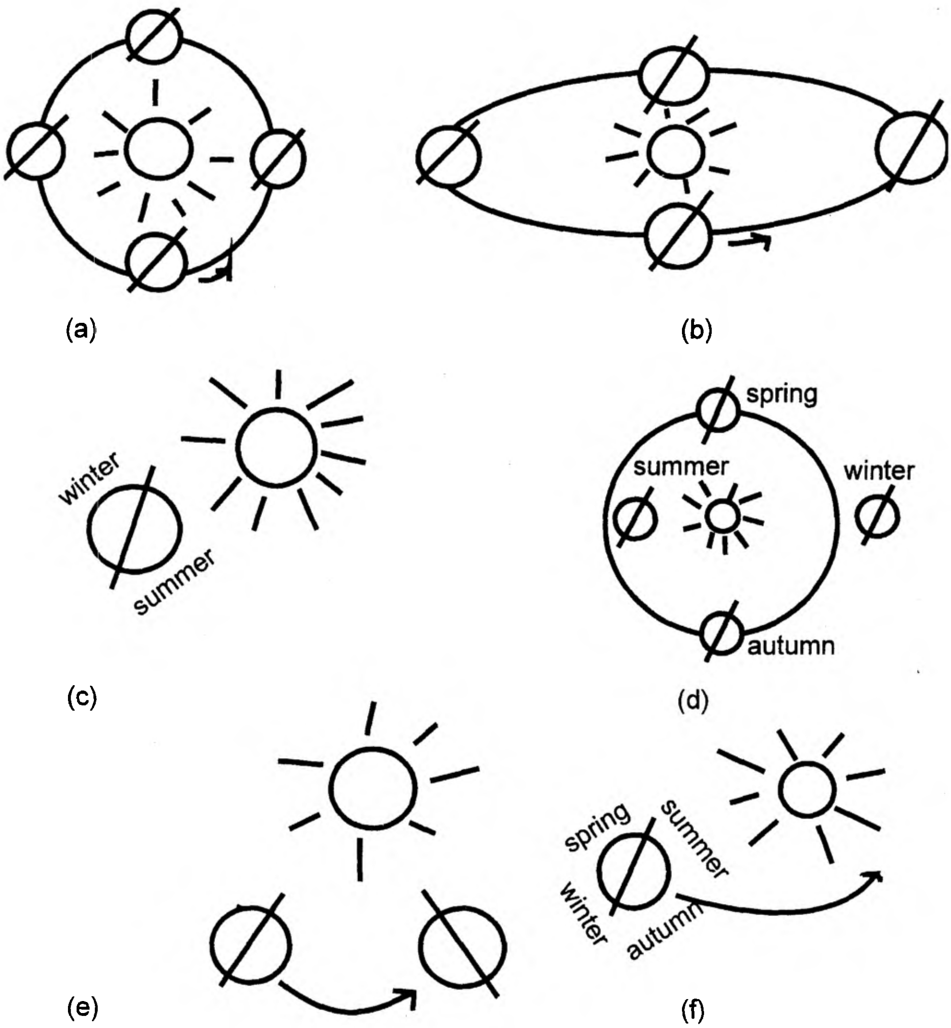


(a) (b) (c) (d)

II **Aggregate** (intermediate) answers contain either non-exact school knowledge or everyday and school knowledge is connected in a peculiar way. Several subcategories of such answers were found. In mixed answers student either relates all s/he remembers (explaining reasons for either day/night variation or seasonal changes by the fact that the Earth revolves around the axis and around the Sun) or confuses the reasons for day/night and seasonal changes (i.e., gives the wrong movements of the Earth). The same movements are shown on illustrations (Figure 1b, Figure 2c). The Sun-movements answers give the reason for changes in the Sun rotating around the Earth (cf. synthetic models by Vosniadou, 1992.) . It is also a causal explanation but actually wrong: it is taught in school that not the Sun but the Earth revolves around. In illustrations, the revolving Sun is drawn (Figure 1c). Strange illustrations give a scheme (usually with both the Earth and the Sun on it) which is not physically correct (Figure 1d, Figures 2d–f).

Figure 2

Examples of students' illustrations of seasonal changes



III **Descriptive** answers do not give any causal (physical) reason for the change but either describe what can be seen or felt or give personal explanations (cf. initial models by Vosniadou, 1992). Corresponding illustrations are simple drawings of summer (with flowers and green trees), winter (with snow, snowmen, skiing), day (people working) and night (people sleeping).

Missing (no drawing). All the children gave explanations but several did not illustrate their answers.

A part of the study, analyzing the development of explanations, is published in Kikas, in press.

Results

Textbook discourse

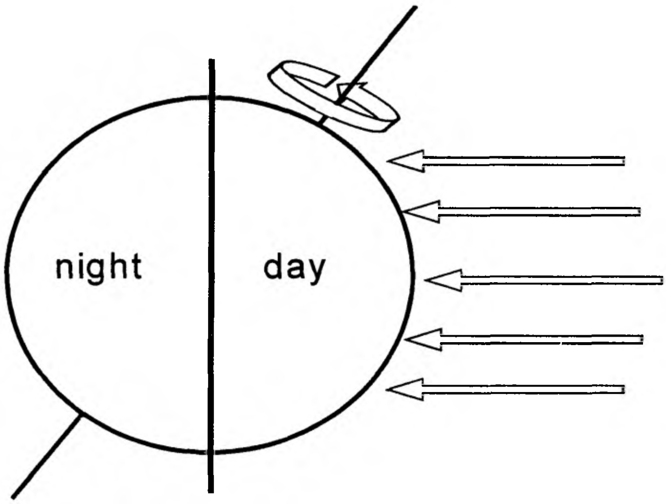
The themes "Day and night variation" and "Seasonal changes" are studied for the first time in the 5th grade in science lessons. Estonian schools have a science textbook (Nilson & Tiits, 1988) and a workbook (Nilson & Tiits, 1989) (for more detailed analysis of these texts see Kikas, In press). The emphasis is on definitions of terms and long descriptions of phenomena. The parts that are stressed are printed in bold and presented separately. The following explanations of day/night and seasonal changes are given: " **Day and night change because the Earth rotates around it's axis, sometimes one side of the Earth is towards the Sun, another times another side, day is on this side of the Earth where there is the Sun", "Seasons change because the Sun warms Southern and Northern Hemispheres differently because the Earth's axis is tilted and the Earth revolves around the Sun".** Both the phenomena are illustrated. These illustrations are given in Figure 3. The answers to the questions in workbook can be found directly from the text.

The book's explanations take into account neither children's naive theories nor stress the critical knowledge necessary for understanding scientific explanations. Even more, the illustration (Figure 3b; the Earth's orbit is drawn as an ellipse) gives countenance to the widespread explanation of seasonal changes that the distance from the Sun accounts for the temperature change (the Earth is closer to the Sun in summer and farther away in winter) (cf. Michaels & Bruce, 1989). Although the Earth's orbit is more or less a circle, it is usually shown inclined which enables to show the angle of the Earth's axis toward the Sun. Just the changing of this angle (that causes the changes in light's angle toward a concrete place on the Earth) causes seasonal changes. If the scheme is not explained by the teacher, it is very difficult to understand its meaning.

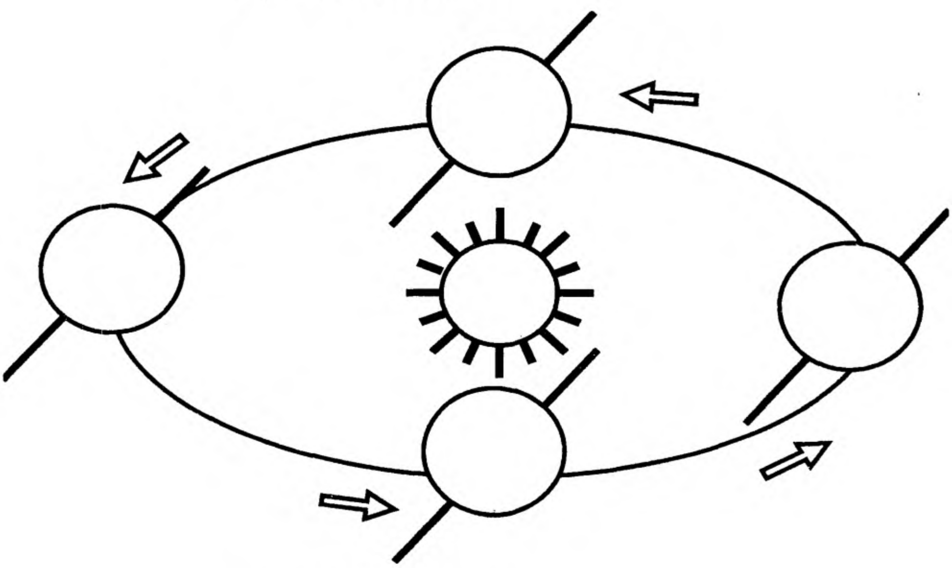
The topic is not taught explicitly in older grades any more. Seasonal changes are implicitly treated in the 7th grade during learning the topic "Climate" (subtopics "The Factors that Influence Climate" and "Climate Zones"). There is no general explanation of why seasons change in the textbook (Jõgi, Kokovik, Kull, Milder & Silam, 1992). But there are long descriptions of different climate zones (equatorial, temperate zone etc.), their geographical position and differences in temperature.

Figure 3

Illustrations in the 5th grade textbook



(a) day/night variation



(b) seasonal changes

Analysis of children's explanations and illustrations

The distributions of explanations and illustrations (number and percentage of students' answers in each category) in different grades is shown in Table 2 (day/night variation) and Table 3 (seasonal changes). Here, the distribution of explanations is shown in columns and distribution of illustrations in rows.

Table 2

The distribution of the explanations and illustrations of day/night variation in different grades in numbers and percentage

Grade	3rd				5th			
Category of explanation/ illustration	Desc-riptive	Aggregate	Exact	All	Desc-riptive	Aggregate	Exact	All
Descriptive	30(66)	3 (7)	5(11)	**38(84)**	6 (8)	0 (0)	0 (0)	**6 (8)**
Aggregate	0 (0)	7(15)	0 (0)	**7(15)**	5 (7)	15(20)	13(17)	**33(44)**
Exact	0 (0)	0 (0)	1 (1)	**1 (1)**	0 (0)	1 (1)	18(24)	**19(25)**
Missing	0 (0)	0 (0)	0 (0)	**0 (0)**	4 (5)	5 (7)	8(11)	**17(23)**
All	**30(66)**	**10(22)**	**6(12)**	**46(100)**	**15(20)**	**21(28)**	**39(52)**	**75(100)**

Table 2 (continued)

Grade	7th				9th			
Category of explanation/ illustration	Desc-riptive	Aggregate	Exact	All	Desc-riptive	Aggregate	Exact	All
Descriptive	4 (8)	3 (6)	0 (0)	**7(14)**	6 (7)	0 (0)	0 (0)	**6 (7)**
Aggregate	10(19)	7(13)	5(10)	**22(42)**	2 (3)	18(23)	2 (3)	**22(29)**
Exact	1 (2)	1 (2)	14(27)	**16(31)**	0 (0)	1 (1)	20(25)	**21(26)**
Missing	3 (6)	4 (7)	0 (0)	**7(13)**	11(14)	11(14)	8(10)	**30(38)**
All	**18(35)**	**15(28)**	**19(37)**	**52(100)**	**19(24)**	**30(38)**	**30(38)**	**79(100)**

It is seen from the Tables that 3rd graders (who have not learnt the topic in school) gave mainly descriptive explanations and illustrations. Students gave either personal explanations (e.g., "day and night change because we need to rest") or descriptions of different seasons, day, and night (e.g., "the Sun shines at daytime and the Moon and stars at night"). Only some students explained phenomena with the movements of the Earth, only one draw an exact scheme illustrating day/night variation. From the 5th grade on, there were less descriptive explanations and drawings given. At the same time, several students did not illustrate their answers at all.

The results show that school teaching has great but different impact on students' explanations and illustrations beginning from the 5th grade.

Explanations. The majority of 5th graders' explanations were exact (see Figure 4). The difference between "exact " explanations in the 3rd and 5th grades was statistically highly significant; $\chi^2(1)=18.52$, $p=0.0000$ (for day/night variation) and $\chi^2(1)=38.96$, $p=0.0000$ (for seasonal changes). There were less exact answers in the 7th and 9th grades than in the 5th grade. The difference was statistically significant between the 5th and the 7th grades for explanations for seasonal changes ($\chi^2(1)=9.59$, $p=0.002$); other changes were not statistically significant ($\chi^2(1)=2.96$, $p=0.085$ for day/night variation between the 5th and 7th grade and $\chi^2(1)=3.06$, $p=0.08$ for day/night variation; $\chi^2(1)=2.16$, $p=0.14$ for seasonal changes between the 5th and 9th grades).

Table 3

The distribution of the explanations and illustrations of seasonal changes in different grades in numbers and percentage

Grade	3rd				5th			
Category of explanation/ illustration	Desc-riptive	Aggregate	Exact	**All**	Desc-riptive	Aggregate	Exact	**All**
Descriptive	42(92)	3 (7)	1 (1)	**46(100)**	11(15)	0 (0)	1 (1)	**12(16)**
Aggregate	0 (0)	0 (0)	0 (0)	**0 (0)**	3 (4)	10(13)	21(28)	**34(45)**
Exact	0 (0)	0 (0)	0 (0)	**0 (0)**	0 (0)	0 (0)	15(21)	**15(21)**
Missing	0 (0)	0 (0)	0 (0)	**0 (0)**	4 (5)	3 (4)	7 (9)	**14(18)**
All	**42(92)**	**3 (7)**	**1 (1)**	**46(100)**	**18(24)**	**13(17)**	**44(59)**	**75(100)**

Table 3 (continued)

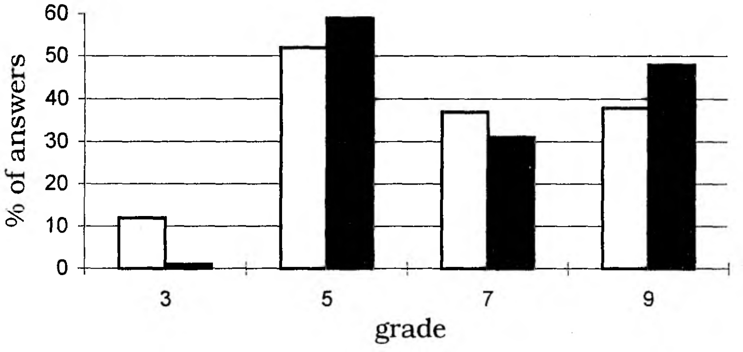
Grade	7th				9th			
Category of explanation/ illustration	Desc-riptive	Aggregate	Exact	**All**	Desc-riptive	Aggregate	Exact	**All**
Descriptive	7(13)	0 (0)	0 (0)	**7(13)**	7 (9)	1 (1)	0 (0)	**8(10)**
Aggregate	3 (6)	7(13)	4 (8)	**14(27)**	2 (2)	12(15)	6 (8)	**20(25)**
Exact	0 (0)	4 (8)	12(23)	**16(31)**	0 (0)	0 (0)	23(29)	**23(29)**
Missing	11(21)	4 (8)	0 (0)	**15(29)**	8(10)	12(15)	8(11)	**28(36)**
All	**21(40)**	**15(29)**	**16(31)**	**52(100)**	**17(21)**	**25(31)**	**37(48)**	**79(100)**

Illustrations. Only a quarter of 5th grade students showed exact movements of the Earth on their drawings (see Tables 2–3), but illustrations of 44% of 5th graders were aggregate, combining information learnt in school and seen by one's own eyes. There were less aggregate illustrations in the 7th and 9th grades but the percentage of exact illustrations did not grow.

Consistency in answers. First, there was a high consistency both in explanations and illustrations (i.e., using the same category answer for day/night and seasonal changes) in all grades; Kendall' s $\tau=0.67$, $p=0.000$ (for explanations) and $\tau=0.53$, $p=0.000$ (for illustrations). So, students tend to explain and illustrate both phenomena relatedly, in the same manner (cf. Vosniadou & Brewer, 1994). Second, there was a consistency in explanations and illustrations (i.e., using the same category answer for explaining and drawing) in all grades, Kendall' s τ= 0.71, p=0.000 (for day/night variation) and τ =0.773, p=0.000 (for seasonal changes).

Figure 4

Distribution of exact explanations



☐ day/night variation ■ seasonal changes

Qualitative changes in explanations. Strong impact of teaching on students' explanations was seen in the 5th grade. 5th graders explanations were quite similar to each other, expressed in book's words mostly.

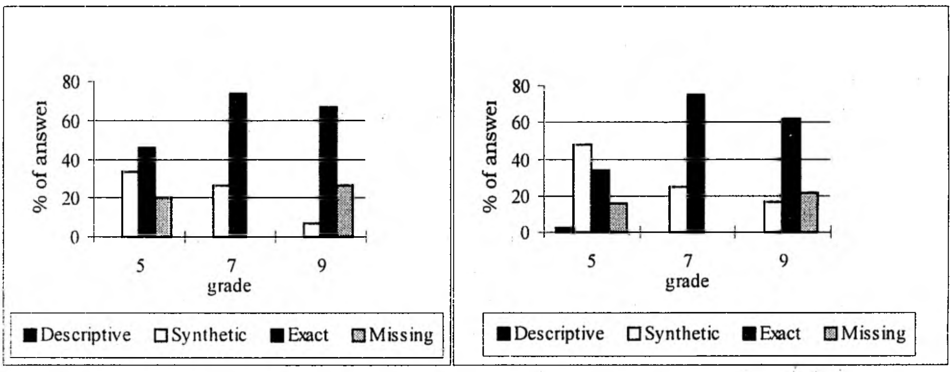
But the impact of teaching on explanations did not last long. There was more variety in 7th and 9th graders' answers than in 5th graders ones. The 5th grade science textbook was not the main source of the knowledge any more. Descriptions were longer and of different aspects of changes, some of them being remarkably poetic (see the 5th and 11th answers in Table 1). The impact of teaching was seen in new themes driven from lately studied topics. 31% of 7th graders (5% of 9th graders) referred to our geographical position, climate zones, and the equator while explaining the reasons for seasonal changes (see the 9th answer in Table 1). The latter were the concepts that had been studied in the 7th grade (4 months before the questioning of the students). Older students used more scientific terms in their answers (cf. Sadler, 1987).

Differences in explaining and illustrating phenomena. After learning a topic in school (5th grade), students gave explanations that based on the textbook (see Table 1, exact explanations). They had memorized the textbook's knowledge quite exactly. At the same time, the students illustrated their answers quite differently. It is seen from Tables 2–3 that part of 5th graders whose explanations are exact illustrate their answers correspondingly (i.e., with exact drawings). Others either do not illustrate their answers at all or do it with aggregate drawings. Also, students who have not differentiated between exact reasons for changes (aggregate explanations) tend to draw aggregate illustrations. It is also seen from Tables 2–3 that in all grades, usually, if a student gives an exact illustrations, s/he also gives an exact explanation.

We analyzed separately the distributions of different categories of illustrations which accompanied exact explanations in grades 5–9 (see Tables 2–3 columns exact and Figure 5). The percentage of exact illustrations increases and of aggregate illustrations decreases in older grades. The difference between the percentages of exact illustrations is statistically a borderline for day/night variation (p=.027 between 5th and 7th grades; p=.047 between 5th and 9th grades) and significant for seasonal changes (p=.003 between 5th and 7th grades; p=.007 between 5th and 9th grades). The difference between the percentage of aggregate illustrations is statistically nonsignificant between 5th and 7th grades (p=.295 for day/night variation and p=.06 for seasonal changes) but significant between 5th and 9th grades (p=.002 for both phenomena).

Figure 5

Distribution of illustrations accompained with exact explanations



(a) day/night variation (b) seasonal changes

Discussion

In the present investigation, the development of children's ability to explain and illustrate day/night variation and seasonal changes and the impact of education on this development was studied. We showed the strong but different influence of teaching on students' verbal explanations and drawings. Our results also raised the question of assessing students' understanding of knowledge in general.

Third graders who had not studied the topic in school gave mainly everyday explanations and illustrated their answers accordingly. The strong impact of teaching on students' explanations was determined 6 months after learning the topic in school: the majority of 5th graders' explanations were the same as in the textbook, i.e., students were able to reproduce textbook explanations (see Figure 4). There were less exact and more aggregate explanations in 7th and 9th grades which means that school explanations have remained too abstract for many students, and they have not been able to integrate school and everyday knowledge. These are the verbalisms where students do not acquire concepts but words and rely on their memory not on thinking (cf. Vygotsky, 1994c). The influence of teaching on explanations was also seen in new themes driven from the lately studied topics: one third of 7th graders referred to our geographical position, and climate zones while explaining the reasons for seasonal changes. Also, older students used more scientific terms (cf. Sadler, 1987).

In school teachers assess the acquisition and understanding of students' knowledge mainly with such questions to which answers are given in the textbook and stressed by the teacher, i.e., with factual questions (cf. Vosniadou, 1994). Actually, this verbal acquisition of knowledge is quite illusory.

We could show that using drawings enables to determine this speciousness. The 5th graders who gave exact explanations divided into two groups on the basis of their drawings (see Figure 5). The illustrations of the first group were exact, i.e., consonant with explanations but of the second group aggregate, i.e., inconsonant with explanations. The understanding of students in these groups is different. The first group has an integrated conception of the phenomena which is also in accordance with the knowledge that had been taught in school. The second group has nonintegrated knowledge: their explanations and illustrations stand separately. The fact that the students have not understood the phenomena but only memorized texts is seen from the aggregate nature of their drawings.

Aggregate illustrations are based on textbook's illustrations but usually also contain something (some assumptions) of everyday experience and are comparable to synthetic models or misconceptions according to Vosniadou (1992, 1994). It is seen from the illustrations that these children have quite a vague idea of the movements of the Earth (e.g., Figures 2d–f). They have memorized the verbal explanation "The Earth revolves around the Sun" but have not understand its real meaning. Also, in several illustrations the idea of fixed up-down direction is expressed. For example, the Sun shines at the top as we see it in everyday life but the day/night are shown in the place where they are drawn in the textbook (Figure 1d, cf. Figure 3). The same idea is expressed on Figure 2e while illustrating seasonal changes. According to Vosniadou (1994), it is one of the ontological presuppositions children use to construct their initial and synthetic mental astronomical models. The differences between their explanations and illustrations, and especially the strange form of illustrations shows that these students do not understand phenomena although their verbal explanation is correct.

It is possible that these students will later revert in their explanations to aggregate or even descriptive answers. These changes were shown in our longitudinal study (unpublished data). The results of the present cross-sectional study also affirm the tendency: in older grades, students gave less exact explanations, but the amount of exact illustrations did not grow. Students acquired verbal facts and illustrations separately at first, memorizing mainly the verbal school knowledge (as it is usually demanded by the teacher) but did not draw their illustrations on the basis of the explanations. Our results show that teaching where the stress is on memorizing can give outwardly good results shortly after learning the topic in school. Students include new school knowledge (e.g., geographical zones) into their answers very easily. But as the teaching does not encourage the integration of everyday and school knowledge, students forget the explanations and turn back to their everyday explanations again. The results have also shown that learning by rote is not the same as achieving understanding.

Exact explanations were mainly accompanied by exact illustrations in 7th and 9th grades (see Figure 5). It shows the real understanding of phenomena: these students have integrated the school knowledge with their everyday knowledge (Vygotsky, 1994c). At present they are able to use different mediational means (verbal explanations and illustrations) in a consistent manner.

It seems that asking students to illustrate their explanations is a good method to gain a deeper insight into students' understanding. Another possibility is used by Vosniadou *et al.* (Vosniadou, 1992, 1994; Vosniadou & Brewer, 1992, 1994). They asked generative questions which confront students with phenomena about which they do not have direct experience and about which they have not received any explicit instruction. Although clinical interviews have become popular in assessing students' misconceptions (Bell, 1995) it is probably too time-consuming to use interviews in usual classroom assessment by teachers.

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— Alternative teaching methods.

— Development of concepts of natural sciences.

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