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THE IMPACT OF TEACHING ON STUDENTS' EXPLANATIONS OF ASTRONOMICAL PHENOMENA

The influence of school education on children's explanations of astronomical phenomena (day/night variation and seasonal changes) was studied. First, we analyzed how the topic was taught in textbooks. Secondly, 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 established. 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 to new topics learned at school emerged in the answers.

Introduction

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

Scientific explanations are learned at school. In contrast to everyday experiences, verbal descriptions, explanations and logical argumentations are of great importance here as much talk concerns 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 on 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 & Tiberghien, 1985; Vosniadou, 1992; Chi, Slotta & Leeuw, 1994; Tiberghien, 1994). It has

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been shown that children learn from school mainly knowledge that does not contradict their everyday experiences. Students also make compromises, forming synthetic models (also called misconceptions) which are attempts to integrate scientific and everyday information (Vosniadou, 1992).

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 & Grzybowski, 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 knowledge.

Astronomy is one of the fields where everyday models differ substantially from scientific explanations of phenomena. Several studies have shown that children's astronomical models are consistent and difficult to change. 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 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 said more often that the Sun revolved around the Earth and older students that the Earth spun.

Ideally, synthetic models are replaced with scientific ones at school (e.g., day/night variation is explained by the fact that the Earth spins). 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 courses 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 the Estonian textbook, the students' explanations two months after learning the topic at school were very different. Estonian students had memorized the explanations quite well and answered the interviewer with words from the book (Kikas, 1992; 1994).

But the impact of learning did not last long. We interviewed the same students four 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 it into their everyday knowledge they returned to everyday explanations afterwards.

Method

Subjects

Our investigation was conducted in 4 general 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. Special attention was paid to the way 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 vary?

* 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). The text contains 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 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 vary because the Earth rotates around its axis, sometimes one side of the Earth is towards the Sun, other times the other 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 since the Earth's axis is tilted and the Earth revolves around the Sun".*

Table 1. Distribution of explanations of day/night variation in different grades (frequencies and percentages)

Grade	Category of explanation												
	School-based						Common-sense (Others)						Total
	Exact		Mixed		Σ		"Sun"		Descriptive		Σ		
	n	%	n	%	n	%	n	%	n	%	n	%	n
3rd	6	13	5	11	11	24	5	11	30	65	35	76	46
5th	39	52	20	27	59	79	1	1	15	20	16	21	75
7th	19	37	11	21	30	58	4	8	18	35	22	43	52
9th	30	38	19	24	49	62	11	14	19	24	30	38	79

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 the workbook can be found 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 (Jygi 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 explanations (see above). In "Mixed" answers the 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 its 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[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 (1994) classification schema, exact explanations can be identified as scientific, mixed and Sun answers as synthetic, and descrip-

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

Table 2. Distribution of explanations of seasonal changes in different grades (frequencies and percentages)

Grade	Category of explanation												
	School-based						Common-sense (Others)						Total
	Exact		Mixed		Σ		"Sun"		Descriptive		Σ		
	n	%	n	%	n	%	n	%	n	%	n	%	n
3rd	1	2	2	4	3	6	1	2	42	91	43	93	99
5th	44	59	12	16	66	75	1	1	18	24	19	25	84
7th	16	31	11	21	27	52	4	8	21	40	25	48	52
9th	37	47	14	18	51	65	11	14	17	21	28	35	79

tive answers as 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).

The 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).

It can be seen from the tables that 3rd graders gave mainly descriptive answers (65% for day/night variation and 91% for seasonal changes). Still, some 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; $c^2(1)=35.06$, $p=0.0000$ (for day/night variation) and $c^2(1)=52.99$, $p=0.0000$ (for seasonal changes).

There were fewer 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 ($c^2(1)= 6.44$, $p=0.01$ for day/night variation; $c^2(1)=7.01$, $p=0.008$ for seasonal changes) and for explanation of day/night variation between the 5th and 9th grades ($c^2(1)=5.08$, $p=0.024$) but nonsignificant for seasonal changes ($c^2(1)=1.85$, $p=0.173$).

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, $c^2(1)=24.27$; $p=0.0000$ (for seasonal changes) and $c^2(1)=18.8$; $p=0.000$ (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.

Content of the Answers

The majority of 3rd grade answers were either personal explanations (e.g., "Day and night vary 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 in the textbook. 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 its 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, reported everything they remembered.

There was more variety in 7th and 9th graders' answers. The 5th grade science textbook was no longer the main source of knowledge. 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, e.g., "A morning starts with sunrise. The higher the Sun the more beautiful the day becomes. 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 derived 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. E.g., "Seasons change because we do not live near the 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 soon forgot it. At the same time, new themes, learned in older grades, emerged in the answers.

Third grade students had mainly naive-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 words quite exactly. But as the students did not integrate their everyday and school knowledge, they quickly forgot the latter and dropped down to previous explanations. Many 7th and 9th grade students had forgotten book 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 that had 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 earlier findings. Both Sadler (1987) and Michaels and Bruce (1989) found that students had not acquired scientific explanations even right 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 fewer 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 highly trained during lessons. Students memorized the new information but did not discuss 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 strong immediately after learning but not in the longer perspective.

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