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Students' understanding of cloud and rainbow formation and teachers' awareness of students' performance

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ABSTRACT

This study describes primary school students' knowledge about rainfall, clouds and rainbow formation together with teachers' predictions about students' performance. In our study, primary school students' ($N = 177$) knowledge about rainfall and rainbow formation was examined using structured interviews with open-ended questions. Primary school teachers' ($N = 110$) awareness of students' understanding was measured with questionnaires and the results will be discussed in relation to teaching experience and the use of different teaching practices. Our results show that students in every grade hold a wide-ranging set of misconceptions that reflect different combinations of their own understanding and learnt scientific knowledge. Teachers tended to overestimate students' performance and described second-grade students' knowledge more accurately than fourth- and sixth-grade students' knowledge. Teachers with less teaching experience were found to less overestimate and more underestimate sixth-grade students' knowledge than teachers with more teaching experience.

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Misconceptions; synthetic concepts; teachers' awareness; constructivist learning

Introduction

The constructivist perspective sees learning as integrating new knowledge into an existing knowledge system with reconstructing the latter as needed (Scott, Asoko, & Leach, 2007; Treagust & Duit, 2008). Today, knowledge reconstruction is seen as a more dynamic, ongoing process than as described in the 'classical approach' to conceptual change (Vosniadou, 2008). Learning scientific concepts is described as gaining overall more complex ways of thinking about different phenomena (Assaraf & Orion, 2005; Smith, Wiser, Anderson, Krajcik, & Coppola, 2004). Therefore, new approaches of effective teaching are also discussed and offered (Gadgil, Nokes-Malach, & Chi, 2012).

Researchers emphasize the role of students' previous understanding about different phenomena before studying them at school and how such understandings influence the way they interpret the new information taught at school (Chi & Slotta, 1993; diSessa, Gillespie, & Esterly, 2004; Ioannides & Vosniadou, 2002). Misconceptions are also often shown to result from a process whereby new abstract scientific information is synthesized

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with existing knowledge (Kikas, 2003; Vosniadou, 1994, 2008). In our study, we use the term 'misconception' to refer to students' understanding that differs from scientific viewpoint and which can occur before formal learning at school as well as after it (Andrews et al., 2012). Knowing misconceptions that can arise in different periods of learning is essential for enabling teachers to plan their teaching more effectively. Similar studies have devoted limited attention to weather-related topics, despite the fact that they provide an important basis for understanding significant topics like climate change and global warming (Henriques, 2002; Villarroel & Ros, 2013). Thus, the first aim of our research is to describe second-, fourth-, and sixth-grade students' understanding of rainfall and rainbow formation.

In constructivist framework, teacher's role is likened to an autonomy-supportive coach who encourages students to think about their knowledge and helps to bring out the differences between scientific and students' personal viewpoints to promote meaningful learning (Gunstone, Fensham, & Gunstone, 2013). Theory of Pedagogic Content Knowledge (PCK) highlights that changes in students' understandings might also be related to their teachers' knowledge about children's minds and learning (Fulmer, 2013; Hill, Ball, & Schilling, 2008; Strauss, 1993). First, to effectively support students' learning, teachers should acknowledge and accept that students' understanding can differ from scientific knowledge in various ways (Duit, Treagust, & Widodo, 2008). Studies have shown that teachers often interpret misconceptions as evidence of children's incorrect understanding or 'lack of understanding' rather than 'understanding differently' (Duit et al., 2008; Gomez-Zwiep, 2008; Nussbaum & Novick, 1982), which decreases the possibility to consider misconceptions as foundations upon which a new concept could be built and use teaching strategies that may help students reconstruct their understanding (Duit et al., 2008). Second, teachers should know the most common misconceptions their students might encounter and use strategies to deal with those misconceptions. Different beliefs about teaching as well as a lack of time or strategies for dealing with students' understandings can lead teachers to under- or overestimate students' conceptual understanding (Diakidoy & Iordanou, 2003). An overestimation of students' knowledge is an obstacle to effective science instruction because teachers might spend less time on relevant topics or elicit connections that might not be important for students (Diakidoy & Iordanou, 2003; Yang, Noh, Scharmann, & Kang, 2013). Similarly, underestimation can lead teachers to concentrate on a topic that might not be relevant for students, thereby affecting students' learning motivation (Urhahne, Chao, Florineth, Luttenberger, & Paechter, 2011). To the best of our knowledge, teachers' perceptions of students' understanding, together with research about students' knowledge of weather-related areas, have not been studied. Thus, the second aim of the current study is to analyse primary school teachers' awareness of the percentage of correct answers among students and possible misconceptions and also describe factors that might be related to teachers' overestimation of students' understanding. In addition to providing quantitative results, this study offers examples of teachers' descriptions of students' possible misconceptions in the second, fourth, and sixth grades.

Children's ideas in weather-related areas

Previous research into children's understanding of weather-related phenomena has been mainly driven by developmental theories which have described age-related differences regardless of specific learning opportunities (for an overview, see Henriques, 2002). Here, misconceptions have been seen more as obstacles that need to be brought out, removed and replaced (Maskiewicz & Lineback, 2013). It has been shown that 5–7-year-old children perceive clouds as solid bags that hold rain; they might also think that rain does not come from clouds at all (Bar, 1989; Stepans & Kuehn, 1985). Children from 7 to 9 years old tend to believe that rain does exist inside clouds, but wind is needed for it to start to rain while older children tend to give answers related to water cycle. Describing rainbow formation, primary school children tend to think that rainbow is formed because of the windy weather, that different colours of the rainbow are formed by the variously coloured raindrops, and that rainbows indicate that there is no more water in the atmosphere so it will not rain for a while (Taiwo, Ray, Motswiri, & Masene, 1999). Research findings also indicate that younger children tend to relate rainbow formation to religious causes (Stepans & Kuehn, 1985) and believe that a rainbow disappears as soon as someone touches it. Children argue that they cannot slide on a rainbow because they would fall off, and think that a rainbow is formed because the Sun wants to push the clouds away (Siry & Kremer, 2011).

Other researchers have treated misconceptions as foundations for further and deeper understanding (Duit et al., 2008; Maskiewicz & Lineback, 2013). In accordance with these ideas, several replacements for the word 'misconception' have been offered (e.g. preconception, alternative conception, naïve idea, common-sense conception), but no consensus has been reached (Crowther & Price, 2014; Maskiewicz & Lineback, 2013). Thus, in our study, we still use the term misconception, but relying on the constructivist perspective, we conceptualize misconceptions as opportunities for further deeper learning and, similarly to several researchers, define misconceptions as imprecise ideas and understanding that can precede instruction at school and also can be driven by instruction (Crowther & Price, 2014). In line with these ideas, a Learning Progressions (LP) construct is offered to describe moving from fragmented approach of science learning to a more unified set of ideas where learning means developing more complex ways of thinking about different phenomena (Smith et al., 2004).

Understanding the formation of misconceptions and paying more attention to them in classroom is also important, as it is shown to be possible that children may use similar words to explain phenomena, but their understanding and meaning behind the words might differ (Kikas, 2010; Tytler, 2000; Vygotsky, 1934/1997). For instance, Tytler (2000) showed that although students in first and sixth grades gave similar answers describing various concepts, their level of understanding was different in linking and distinguishing ideas of evaporation and condensation.

Teachers' awareness of students' knowledge and its importance

PCK student-centred approach highlights the importance of students' previous knowledge and skills which teachers should be aware of to better support meaningful learning (Shulman, 1987; Strauss, 1993). Studies have shown that teachers tend to overestimate students' performance. For example, Diakidoy and Iordanou (2003) found that more than half of the surveyed teachers tended to overestimate pupils' understanding of the concept of energy in sixth grade. Similarly, Yang et al. (2013) reported that teachers overestimated the number of students holding accurate scientific concepts in the area of evaporation. Lightman and Sadler (1993) found that teachers correctly predicted students' initial performance (before learning), but vastly overestimated their gain in knowledge after an astronomy course. In addition, they found that teachers' predictions did not vary with students' age (ninth- to twelfth-grade students). Diakidoy and Iordanou (2003) argued that teachers' tendency to overestimate students' prior knowledge might be reflected in the classroom in terms of less instructional time, which in turn leads to the persistence of misconceptions even after learning. Yang et al. (2013) added that, due to their overestimation, teachers are less likely to present appropriate discrepant events to arouse students' cognitive conflict and reconstruct their cognitive structure.

Teachers' underestimations in terms of students' understanding have been less reported, but researchers have argued that teachers underestimate the variety of different ideas that students' might have and how their knowledge actually differs from each other due to their previous understandings (Hammer, 2000). Misconceptions are described by many teachers as resulting from external sources (cartoons, conversations with friends and parents), rather than originating in students' own thinking or reflecting the idea of misconception as students' differently interpreted information (Gomez-Zwiep, 2008). Teachers also tend to view misconceptions as gaps in knowledge that need to be filled in contrast to constructivist ideas where misconceptions are seen as dynamic resources for deeper understanding where scientific information may be a new source for different misconceptions (Gomez-Zwiep, 2008; Kikas, 2003; Vosniadou, 2008). Thus, teachers' awareness may relate to their understanding of the overall learning process and the formation process of misconceptions.

Moreover, findings indicate that teachers with different teaching experiences conceptualize students' knowledge differently. Expert teachers tend to have more complex understanding about students' prior knowledge and they see students' own ideas and explanations as important components of the formation process of scientific knowledge. On the other hand, novice teachers seem to consider prior knowledge as something that students formally know (or do not know) about a concept and that misconceptions are easily replaced with new correct information (Meyer, 2004). Practising teachers tend to be more accurate than preservice teachers in predicting students' prior knowledge (Diakidoy & Iordanou, 2003). However, the ability to address misconceptions does not necessarily develop with experience (Diakidoy & Iordanou, 2003; Gomez-Zwiep, 2008; Yang et al., 2013). In addition, preservice teachers are more likely to underestimate students' performance than teachers with more teaching experience (Diakidoy & Iordanou, 2003). Teachers' awareness can also be related to their preferred methods of teaching. Yang et al. (2013) showed that teachers with greater awareness of students' knowledge tend to use less traditional methods of teaching while this awareness was not related to using constructivist strategies (Yang et al., 2013).

Knowing students' current knowledge (that may include misconceptions) is essential in order to conceptualize learning as construction and re-construction of knowledge and apply constructivist teaching methods (Park & Oliver, 2008). Namely, during this teaching process, teachers should first identify students' current knowledge and facilitate the construction (modification and replacement) of their own knowledge based on what and how they know in order to support meaningful learning (Kerr, Beggs, & Murphy, 2006).

Aims of the current study

This study is comprised of two parts; the first part examines children's understandings and the second part explores teachers' awareness of these understandings (predictions of students' scientific answers and knowledge about possible misconceptions) as well as factors related to their awareness. We studied primary school students and teachers because weather elements are an important part of the primary school science curricula and knowing these topics creates further basis for understanding climate change and other weather-related processes. Clouds, rain, and rainbow are also commonly occurring phenomena, but their scientifically explained formation process is difficult to understand. Thus, it is important to describe understanding related to these topics. The study was carried out in Estonia, where children start school at the age of seven and weather-related topics are included in the national curriculum for lower and upper primary school (Vabariigi Valitsus, 2002/2010). The participating children (second, fourth, and sixth graders) had studied weather topics to different extents. The participating teachers had different educational backgrounds and experience. Primary school teachers were selected because they are expected to teach students in all first six grades and thus should know the peculiarities of students from this age range. As the Estonian educational system has changed considerably during the last few decades, putting more emphasis on constructivist learning theories and individualization in teaching (Uibu, Kikas, & Tropp, 2011), it was expected that participating teachers differ in their preferred teaching methods.

Study 1

Aims, research questions and hypotheses

The aim of the Study 1 was to describe second-, fourth-, and sixth-grade students' beliefs about rainfall and rainbow formation. We were interested in how students in different grades describe rainfall and rainbow formation and as these topics are covered in lessons at the primary school level, we expected that the percentage of children giving correct answers would overall be higher in higher grades. However, as previous studies have shown that it is difficult for primary school children to truly understand cloud and rainbow formation and that they have formed many different misconceptions (Bar, 1989; Saçkes, Flevares, & Trundle, 2010; Stepans & Kuehn, 1985; Taiwo et al., 1999), we expected to find misconceptions in all grade levels. We also aimed to describe widespread misconceptions (in association with learnt topics) in second, fourth, and sixth grades.

Method

Sample

Fifty second graders (27 boys; ranging in age from 8 to 9 years), 66 fourth graders (36 boys; ranging in age from 9 to 11 years), and 61 sixth graders (34 boys; ranging in age from 11 to 12 years) participated in the study. The sample was selected from 11 schools in one large town in Estonia and included children from an Estonian-speaking and average socio-economic status background.

Procedure

An informed consent was asked from parents and school management before conducting the research. Interviews were conducted only with children who had been approved to participate in the study. Children were interviewed individually in a separate room at school. Interviews were conducted by three psychology students who prepared to behave similarly and give identical instructions. The same questions were asked from all the children. Questions were asked in the same order every time, and no help was given to the children when they were answering. Interviews with children were first audio-recorded and then transcribed by the same interviewer.

Interview questions

Interview questions were formulated based on a previous study (Taiwo et al., 1999). All the questions are shown in Table 1. Answers to open-ended questions were categorized using similar schema as in Kikas (2010) and Malleus, Kikas, and Marken (in press). Here, we separated correct or scientific answers (e.g. 'It starts to rain because water droplets join into bigger droplets and then they are too heavy and start to fall down', 'A rainbow occurs because sun and rain happen at the same time', 'You can't go through the bottom of the rainbow because a rainbow is light and the position of the rainbow changes when you try to get closer') and misconceptions. Specific examples of the children's misconceptions are described in the Results section. Missing answers (statements in which the child claimed that she/he did not know the answer) were excluded from the analysis.

Detailed coding instructions that were based on a pilot study and previous research were used by three different researchers to code answers from the interviews. If an answer did not match exactly with any of the examples, it was written down (13% of all answers in second grade, 10% in fourth grade and 16% in sixth grade) and analysed in meetings with other coders and experts.

Results

Students' correct knowledge and misconceptions

The percentage of students, who gave correct answers in each grade level, is shown in Table 1. Between-grade differences were examined using a Pearson chi-square analysis.

Table 1. Percentage of correct answers in various grades.

Questions asked from students	Grade 2 %	Grade 4 %	Grade 6 %	p[a]
(1) Why does it start to rain?	14	18	34	6 > 4 = 2
(2) How does rain get into the cloud?	23	28	58	6 > 4 = 2
(3) How does the rainbow occur?	78	88	79	6 = 4 = 2
(4) When does the rainbow disappear from the sky?	80	86	79	6 = 4 = 2
(5) Is it possible to pass from under the rainbow?	42	70	66	6 = 4 > 2
(6) Explain why it is or isn't possible to pass from under the rainbow.	12	24	48	6 > 4 > 2
(7) What shape is the rainbow?	82	91	89	6 = 4 = 2

[a]Difference between grades ($p < .05$).

Table 2. Examples of most common misconceptions in different grades.

Questions	Answers by grade: Second grade	Fourth grade	Sixth grade
Why does it start to rain?	It is stormy outside Flowers or trees want to drink water Otherwise land will be too dry	Clouds are full of fog The cloud evaporates There are dark clouds in the sky	Clouds are full of fog Barometric pressure changes too quickly There are too much moisture in the air
How does rain get into the cloud?	Water gets into the cloud by disappearing from the ground It comes from the ground Rain/fog comes from the ground with wind and forms clouds	It comes from the ground Rain/fog comes from the ground with wind and forms clouds Rain forms in the atmosphere	It comes from the ground With the help of barometric pressure Rain forms in the atmosphere
How does the rainbow occur?	Rainbow occurs when you want the sky to be beautiful after rain Rainbow occurs when there are dark clouds in the sky You need sunshine for rainbow to appear	Rainbow is all the time in the sky and sun makes it visible You need sunshine for rainbow to appear Rainbow appears only when it rains Sun reflects on the sea and forms a rainbow Rainbow occurs when sun shines and fog is in the sky	Rainbow occurs when hot and cold air come together Sun reflects on the sea and forms a rainbow
When does the rainbow disappear from the sky?	Rainbow is just some time in the sky and suddenly disappears When there are no puddles on the ground anymore When the storm goes away When there are not enough moisture in the sky	When the storm goes away It starts to rain stronger When sun goes behind the cloud When there are not enough moisture in the sky	When sun doesn't reflect anymore When sun goes behind the cloud When there are not enough moisture in the sky
Explain why it is or isn't possible to pass from under the rainbow.	You can't go through the bottom of the rainbow … Because rainbow is in the sky/is far away Because you are on the ground and rainbow is in the sky There is land of fairies behind the rainbow	You can't go through the bottom of the rainbow … Because rainbow is all around the world Because the location of the rainbow can't be determined Because rainbow is in the sky/is far away	You can't go through the bottom of the rainbow … Because rainbow is in the sky/is far away Because the location of the rainbow can't be determined

Significant differences were found in answers to the questions about rainfall ('Why does it start to rain?', 'How does rain get into the cloud?') as students in second, χ^2 (1, $N = 124$) = 4.28, $p < .05$, $r = .18$, and fourth grades, χ^2 (1, $N = 108$) = 3.71, $p < .05$, $r = .18$, gave significantly less scientific answers to both questions than students in the sixth grade. The effects were relatively low for both comparisons, explaining only 3% of the total variance. A significant difference between children's answers in every grade was found for the question about the possibility of going through the bottom of the rainbow, where second-grade students gave significantly less scientific answers than the children in fourth, χ^2 (1, $N = 127$) = 3.49, $p < .05$, $r = .15$, and sixth grades, χ^2 (1, $N = 111$) =18.21, $p < .01$, $r = .40$, while fourth-grade children gave significantly more scientific answers than children in the second grade, χ^2 (1, $N = 116$) = 7.10, $p < .01$, $r = .25$. The effects were low for fourth grade–sixth grade and second grade–fourth grade comparisons, explaining only 2% and 6% of the total variance, respectively. For the second grade–sixth grade comparison, 16% of the total variance was explained.

Examples of common misconceptions that children held in different grades are shown in Table 2.

Study 2

Aims, research questions and hypotheses

The aim of the second study was to delineate primary school teachers' predictions of second-, fourth-, and sixth-grade students' knowledge of weather-related topics as well as describe teachers' knowledge of students' common misconceptions. Teaching experience and instructional practices were also examined as potential factors in the varied accuracy of predictions. The research questions and hypotheses are discussed in the following paragraphs.

The first point of interest was how exact are teachers' predictions of the level of students' correct knowledge of weather-related concepts. Previous studies have shown that teachers tend to overestimate students' performance (Diakidoy & Iordanou, 2003; Yang et al., 2013). Lightman and Sadler (1993) also found that teachers' predictions did not vary greatly with the ages of the students, but teachers vastly overestimated the students' gain in knowledge after the course. Thus, we expected teachers to possibly overestimate students' performance more in the sixth grade (as students should have already learnt those topics in previous grades) than in the second and fourth grades.

The second aim was to find out how teachers describe students' misconceptions. Earlier studies have indicated that teachers also tend to underestimate different ideas and misconceptions that students have and that they tend to see misconceptions as gaps of knowledge not as a synthesis of knowledge from different sources (Gomez-Zwiep, 2008; Hammer, 2000). Therefore, we were interested in what kind of misconceptions teachers would describe and how similar these misconceptions were to the ideas that the students had, when answering to the same questions (see Study 1).

Finally, we were interested whether teachers' precision in their predictions was related to their teaching experience and reported use of different teaching practices. Previous findings about the relationships between teachers' predictions and their teaching experience have been inconsistent. Although expert teachers have been shown to be more aware of students' understanding than novice teachers (Meyer, 2004), some studies have not found links between teaching experience and overrated answers or correct predictions (Gomez-Zwiep, 2008; Yang et al., 2013). To explain these findings, researchers have emphasized that it is not teaching experience per se, but teachers' skills in understanding and applying constructivist strategies which should be considered (Gomez-Zwiep, 2008; Yang et al., 2013). Yang et al. (2013) also reported that a less frequent usage of traditional teaching methods was related to the teachers' awareness of their students' alternative concepts, but this awareness was not related to constructivist practices in particular. Thus, we also expected that teachers who reported using less traditional teaching methods would also predict more accurately students' knowledge about rainfall, cloud formation, and rainbow formation.

Method

Sample

One hundred and thirteen primary school teachers (all female) participated in the study, but we only used data from 110 teachers whose questionnaires were returned complete. Teachers were selected from 30 different schools from several big towns in Estonia. Teachers were between the ages of 24 and 63 ($M = 4.8$; SD = 10.2). They had an average work experience of 19.4 years (ranging from 2 to 44 years; $M = 19.4$; SD = 9.8) and were teaching children from first to sixth grades. While all the participants filled out the first part of the questionnaire, only 28 teachers answered at least some of the open-ended questions about students' possible misconceptions. Teachers gave more answers to questions about second-grade students' misconceptions and fewer to questions about fourth- and sixth-grade students' misconceptions.

Procedure

Three hundred and fifty-two primary school teachers were asked to participate in a study and answer questions online or on a paper questionnaire that was sent to teachers after they had agreed to participate. Thirty-two percent of teachers agreed to participate in the study. Teachers were guided to think about their teaching process and give honest answers. Feedback, including the average results, was sent to teachers three months after they had completed the questionnaire.

Measures

Awareness of students' knowledge

First, teachers were asked to mark the percentage range of second-, fourth-, and sixth-grade students who gave correct answers to the questions that were asked also from students in Study 1 (see Table 1). Teachers were asked to respond on a scale of 1–5 where: 1 = less than 25% of students, 2 = 26–50% of students, 3 = 51–75% of students, 4 = more than 75% of students, and 5 = all students. In our analysis, we joined together ratings four and five (more than 75% of students and all students) as they were confusing for teachers during filling the questionnaire (the ranges were not well distinguishable for teachers). Teachers' ratings for all seven questions in different grades were compared to the respective percentages of correct answers and then classified as accurate estimates, overestimations, or underestimations. Classification as accurate estimate was marked when teachers' ratings matched with the percentage of students who gave scientific answers. Classifications of under- or overestimations were marked for teachers' ratings that were respectively lower or higher than the real percentage of students who gave correct answers for all questions in different grades. Each teacher's ratings for different questions (7 questions) in all grades (3 grades) got one of three classifications (accurate estimates, overestimations, underestimations). Sums of accurate estimates, over- and underestimations were used in the analyses. The maximum possible score for each grade was seven answers.

In the second part of the questionnaire, teachers were asked to describe the most common incorrect answers that students' in second, fourth, and sixth grades usually give to the same questions.

Teaching practices

Teachers' preferences for different teaching practices were assessed using a questionnaire from a previous study (Uibu et al., 2011). The questionnaire consisted of 5 questions that described different practices on a 5-point scale (1 = 'I never use this practice'; 5 = 'I use this practice all the time'). The scale about the constructivist practices consisted of 3 items ($\alpha = .64$), such as 'Before I start teaching new material, I find out about students' previous knowledge', whereas the scale about teacher-centred practices consisted of two items ($\alpha = .61$), such as 'I assign students to acquire facts and rules.'

Results

Teachers' predictions of students' correct answers

Teachers' predictions of students' correct answers are shown in Table 3 together with the results from Study 1 for students. In predictions about second-grade students' correct answers, the variety in the teachers' answers was greater than in their predictions about higher grades. In predictions about second-grade students' performance, teachers over-rated students answering to questions about rainfall (more than 70% of teachers

Table 3. Teachers' predictions of correct answers and the percentage of students' correct answers.

Question	<25%	25–50%	51–75%	76–100%	Students (%)
(1) Why does it start to rain?					
Grade 2	27.7[a]	26.7	27.7	17.8	14
Grade 4	0.0[a]	15.8	27.7	56.4	18
Grade 6	0.0	3.0[a]	25.7	71.2	34
(2) How does rain get into the cloud?					
Grade 2	27.7[a]	26.7	19.8	25.8	23
Grade 4	0.0	11.9[a]	43.6	44.5	28
Grade 6	0.0	2.0	14.9[a]	83.1	58
(3) How does the rainbow occur?					
Grade 2	21.8	35.6	18.8	23.8[a]	78
Grade 4	1.0	13.9	28.7	56.4[a]	88
Grade 6	0.0	4.0	7.9	88.1[a]	79
(4) When does the rainbow disappear from the sky?					
Grade 2	46.5	23.8	21.8	7.9[a]	80
Grade 4	3.0	24.8	46.5	25.7[a]	86
Grade 6	1.0	8.9	38.6	35.6[a]	79
(5) Is it possible to pass from under the rainbow?					
Grade 2	29.7	34.7[a]	15.8	19.8	42
Grade 4	4.0	11.9	15.8[a]	68.3	70
Grade 6	0.0	8.9	9.9[a]	81.2	66
(6) Explain why it is or isn't possible to pass from under the rainbow.					
Grade 2	39.6[a]	34.7	16.8	8.9	12
Grade 4	1.9[a]	21.8	23.8	52.5	24
Grade 6	0.0	10.1[a]	19.2	70.7	48
(7) What shape is the rainbow?					
Grade 2	2.9	7.9	14.9	74.3[a]	82
Grade 4	0.0	2.0	4.9	93.1[a]	91
Grade 6	0.0	2.0	0.0	98.0[a]	89

[a]The percentage of teachers whose prediction was in accordance with students' answers.

overestimated students' actual performance where less than a quarter of students gave scientific answers to these questions). More underestimations were given to second graders' knowledge to questions about rainbow formation and disappearance from the sky. Here, less than a quarter of teachers thought that over 76% of students would give scientific answers to questions about rainbow formation. In predicting fourth graders' performance, teachers expected more students to give right answers to all questions and thus their underestimates of potential answers about rainbow formation decreased. As students' performance in fourth grade answering to questions about rainfall does not differ significantly from the second graders' performance, but teachers assumed it would, teachers gave even more overestimations to these questions (more than 85% of teachers overestimated students' performance).

In the sixth grade, most teachers expected at least 76% of students to give scientifically correct answers to all questions (except the question about the disappearance of rainbow). As students' performance was better in sixth grade, but not as good as most teachers had expected, a great number of overestimations occurred again. Teachers gave more accurate predictions in all grades to the question about the shape of the rainbow.

Next, we analysed the sums of accurate predictions, overestimates, and underestimates (see Table 4). The Kruskal–Wallis tests with grade as an independent factor and sum scores as dependent variables were carried out separately for each type of estimations. The difference between grades was significant for accurate predictions $H(2) = 9.19$, $p < .01$, overestimations $H(2) = 50.35$, $p < .001$ and underestimations $H(2) = 74.63$, $p < .001$.

Pairwise comparisons with Mann–Whitney test indicated that teachers gave significantly more accurate predictions in predicting second graders' answers compared to predictions to fourth graders' answers, $U = 4273.50$, $p < .01$, $r = .22$. Teachers also overestimated fourth, $U = 3038.50$, $p < .001$, $r = .42$ and sixth graders' knowledge $U = 3098.00$, $p < .001$, $r = .41$ more than that of second-grade students. In addition, teachers underestimated second-grade students' performance more compared to predictions about fourth-$U = 3244.00$, $p < .00$, $r = .39$ and sixth-grade $U = 2191.00$, $p < .001$, $r = .56$ students' knowledge.

Teachers' descriptions of children's misconceptions

Examples of teachers' descriptions of students' misconceptions in different grades are presented in Table 5. When comparing these answers with students' answers in Study 1, we found that teachers' predictions and students' answers were most concordant in answering the question 'Why does it start to rain?'

Teachers' answers were more versatile when describing second-grade students' answers where teachers related possible misconceptions with visible things that children might

Table 4. Descriptive statistics of teachers' predictions of students' scientific answers in different grades.

	Grade 2				Grade 4				Grade 6			
	M	SD	Mdn	Max[a]	M	SD	Mdn	Max[a]	M	SD	Mdn	Max[a]
Accurately predicted	1.75	1.36	2	5	1.16	0.86	1	3	1.50	1.29	1	5
Overestimated	3.25	1.65	3	7	4.55	1.03	5	7	4.63	1.63	5	7
Underestimated	1.97	0.81	2	3	1.29	0.87	1	3	0.86	0.97	1	5

[a]Maximum by grades 7 ratings.

Table 5. Examples of teachers' descriptions of children's misconceptions in different grades.

Questions	Answers by grade: Second grade	Fourth grade	Sixth grade
Why does it start to rain?			
	Cloud goes gray Cloud goes darker[a] It starts to rain, because weather is stormy[a] There are stormy clouds in the sky[a] cloud starts to cry Land is dry[a] There is too much water in the cloud It goes colder/warmer	Wind intensifies Too much moisture is evaporating from the ground[a] Lightning strikes and after that it starts to rain	Gravity pulls the rain from the clouds to come back to the earth
How does rain get into the cloud?			
	Wind blows[a] Snow melts There are clouds that produce rain Clouds come from the warmer country Rain formulates inside the cloud	Wind blows[a] Sun brings the rain from the ground It is all because of the moisture[a]	Storm brings rain from the ground up to the sky
How does the rainbow occur?			
	Sun or wind is needed[a] Rain drops into the sun Leprechaun puts a pot of gold somewhere Sun reflects on the raindrops[a]	Sun reflects on the raindrops[a] It is somehow connected with changing seasons Raindrops are shining	
When does the rainbow disappear from the sky?			
	Disappearance of the rain or the sun[a] Clouds are blown away by the wind[a] Clouds come in front of the sun it is too bright to see the rainbow	Disappearance of the rain or the sun[a] Clouds are blown away by the wind[a] Ground dries Wind starts to blow	Disappearance of the rain or the sun[a] Ground dries[a] Wind starts to blow
Explain why it is or isn't possible to pass from under the rainbow.			
	You can't go through the bottom of the rainbow because it is too far away[a]	Students are starting to realize that rainbow is air and they might answer that you can go through the bottom of the rainbow, because air is all around us	You can go through the bottom of the rainbow until it rains and rainbow goes further when you try to move closer

[a]Similar misconception was common in students' answers.

notice and describe (e.g. clouds go darker and it starts to rain, rainbow disappears when clouds come in front of it, rain gets into the cloud when snow melts) . They also mentioned mystical creatures like fairies and leprechauns. Bringing out fourth-grade students' misconceptions, teachers mentioned similar misinterpretations as in the second grade, but they also added some misconceptions that were more related to students' incorrect understanding of scientific concepts (e.g. rainbow occurs because raindrops are shining, it starts to rain because too much moisture is evaporating from the ground). Describing sixth-grade students' misconceptions, teachers used similar elements as describing younger students' possible misinterpretations, but also added elements from more complex sets of understanding (e.g. gravity is related with rainfall).

Relationships between teaching experience, teaching practices, and predictions of students' answers

Spearman correlation analysis was used to describe relations between teaching experience, teaching practices, and predictions of students' answers. Teaching experience was not significantly related to either constructivist ($r_s = .03$, $p > .05$) or teacher-centred ($r_s = -.14$, $p > .05$) teaching practices. However, teachers who had less teaching experience underestimated more ($r_s = -.27$, $p < .01$) and overestimated less sixth-grade students' performance ($r_s = .23$, $p < .05$). In addition, teachers who reported using less teacher-centred methods in their work underestimated more fourth-grade students' performance ($r_s = -.28$, $p < .05$). Reporting using constructivist practices appeared to have no relation to any specific rating categories.

Discussion

This study provided an overview of children's knowledge about rainfall and rainbow formation, taking into account different periods during which these topics are taught in primary school. We found that children in all grades had difficulties explaining the process of rainfall and rainbow formation in detail, and different misconceptions surfaced in their descriptions. We also described teachers' knowledge about students' possible misconceptions and their predictions about students' performance in these two areas. Our results showed that teachers tend to overestimate students' performance more in older grades and underestimate in second grade. We found that teachers pointed out students' widespread misconceptions in second grade, but were more troubled with explaining how scientific knowledge might induce the emergence of new misconceptions in fourth and sixth grades. Teachers with less teaching experience underestimated more and also overestimated less sixth-grade students' performance.

Students' knowledge of weather-related concepts

Our results showed that children in all grades knew (75–91% scientifically correct answers) that both rain and the Sun are needed for rainbow formation and what a rainbow looks like (factual questions). Children had more problems explaining why it starts to rain and how rain gets into a cloud as well as justifying if a person can pass beneath the rainbow. Although sixth-grade students performed better on these questions, they still had trouble forming their answers (altogether, 14–58% of children gave scientifically correct answers). In previous studies (where differences were found between first- and sixth-grade students' explanations of condensation), it was argued that older students have better linguistic skills to describe their ideas, but they still might have difficulties with and confusion in truly understanding learnt phenomena (Tytler, 2000). Our findings also confirm that even sixth graders had difficulties explaining new ideas and applying their knowledge in novel contexts. Using correct scientific words does not necessarily mean that students thoroughly understand the concept (Kikas, 2005; Tytler, 2000).

Similar to earlier studies, we found various misconceptions. Previous research has demonstrated that second- and fourth-grade students tend to believe that wind is needed for it to start to rain while sixth-grade students use phase changes to describe rainfall (Bar, 1989; Stepans & Kuehn, 1985). In our study, second-grade students related the idea of rainfall with growing trees and flowers, which needed water; they also mentioned stormy weather. Fourth-grade students used more scientific concepts, but in a different context (clouds evaporate), thereby reflecting their confusion with the studied topics. Sixth-grade students' misconceptions were related to other relevant and newly learnt concepts (barometric pressure, air humidity) as well as with the confusion in distinguishing different parts of the water cycle (water vapour and rainfall). This finding confirms the overall idea behind constructivism, where children's misconceptions might vary depending on the combination of their previous experience and newly learnt material at specific grade (Kikas, 2010). When describing rainbow formation, primary school children relate stormy weather to rainbows and think that rainbows indicate that there is no water in the atmosphere (Taiwo et al., 1999). Second graders similarly related dark and stormy clouds with rainbow formation, but did not make connections with the amount of water in the atmosphere. Fourth graders described rainbows as existing in the sky all the time, but only the Sun makes them visible. Students might have an idea that rainbow formation needs the Sun and rain (factual knowledge that is often mentioned by adults), but they construct their own relationships between these two concepts when they need to use their knowledge in novel contexts. Fourth and sixth graders also used the description of reflection and sixth graders added relationships with hot and cold air coming together (probably confusing with other weather processes). Second-grade students also said that rainbows are located too far away to go underneath them. A similar study with younger students showed that 5- and 6-year-old children described a rainbow as a concrete object, not an optical illusion (Siry & Kremer, 2011). Moreover, fourth- and sixth-grade students tried to explain the more abstract notion of a rainbow and used different alternative explanations. For example, they answered that a rainbow encircles the globe or its location cannot be determined.

Teachers' awareness of students' performance

Similarly to earlier studies (Diakidoy & Iordanou, 2003; Yang et al., 2013), we found that teachers tend to overestimate students' performance. Moreover, teachers overrated fourth- and sixth-grade students' performance more compared to second-grade students' performance. Conformably, teachers who described possible students' misconceptions in open-ended questions offered more different ideas describing second-grade students' misconceptions and fewer for sixth-grade students. Similarly, Lightman and Sadler (1993) also reported that teachers overestimated mostly the gain in knowledge after learning. In associations with previous studies, we can suggest that teachers' understanding about how misconceptions form and more generally how learning takes place is crucial to better plan their lessons and reduce overestimations about students' performance (Gomez-Zwiep, 2008; Park & Oliver, 2008). We can hypothesize that teachers tend to believe that students' understanding grows fast after learning and, thus, students should show a better understanding in higher grades. Comparing separately teachers' predictions to different questions, we also found that teachers rated different topics similarly (except question about the shape of the rainbow) and more than 70% of teachers believed that in all topics, more than 75% of students in sixth grade should give scientific answers. In contrast, students answered differently to different questions and it was harder than expected for students to explain when it starts to rain, how rain gets into clouds and why one cannot go through the bottom of the rainbow. Teachers have also been shown to undervalue the complexity of students' misconceptions and how their understanding varies (Hammer, 2000). This can similarly be related to their misinterpretations of students' real understanding. In our study, teachers seemed to be aware that students come to class with a variety of ideas from their own experiences. However, they seemed to be less conscious about how scientific understanding is constructed (i.e. the process) and that new knowledge can be combined with previous ideas in the form of new misconceptions (Ioannides & Vosniadou, 2002; Kikas, 2003). For example, teachers brought out misconceptions that students might have before learning these topics scientifically as students might describe rainfall only in connection with dark clouds or stormy weather and water vapour that disappears. It could also be discussed that misconceptions are described differently in various theoretical frameworks and teachers may believe that misconceptions are more common in younger while as students grow older and have more classes in similar topics, their misconceptions should be replaced with correct understanding (Crowther & Price, 2014; Maskiewicz & Lineback, 2013). It is also shown that teachers tend to view misconceptions as gaps of knowledge where new information should be added for misconceptions to disappear (Gomez-Zwiep, 2008). Our study also confirmed that misconceptions are common even after learning and during learning, new misconceptions may arise (Kikas, 2003; Vosniadou, 1994, 2008). Also, it is important for teachers to apprehend that age does not necessarily determine students' level of knowledge and that it is almost impossible to assume that all students learn as fast as the curriculum advises. We can assume that, if teachers do believe that students learn more effectively than they really do and teachers do not pay enough attention to previous understanding, it is likely that students' alternative understandings persist after learning (Yang et al., 2013).

Teachers' awareness in relation to teaching experience and teaching practices

Different findings have been reported describing relations between teaching experience and teachers' awareness (Gomez-Zwiep, 2008; Meyer, 2004; Yang et al., 2013). We found that teachers who had been teaching for fewer years overestimated less and underestimated more sixth-grade students' performance. Similarly, previous researchers have found that preservice teachers tend to underestimate students more than working teachers (Diakidoy & Iordanou, 2003), but some studies have not found relations between teaching experience and overestimations at all (Gomez-Zwiep, 2008; Yang et al., 2013). As it is highlighted that teachers' awareness may be related to their understanding about students' learning (Gomez-Zwiep, 2008), it may be hypothesized that teachers with less teaching experience conceptualize learning differently. Specifically in Estonia, where more emphasis has been put on applying constructivist ideas on teacher education only in recent years, teachers with less teaching experience may be more aware of the idea that learning as constructing new understanding takes time and even sixth-grade students may have various misconceptions (Uibu et al., 2011). Thus, less experienced teachers may have given less overrated predictions about sixth-grade students' performance.

Similarly to previous studies (Gomez-Zwiep, 2008; Yang et al., 2013), we did not find any relationships between teachers' predictions and their application of constructivist practices, but we found that teachers who reported using more teacher-centred methods in their work were less prone to underrating in their predictions about fourth-grade students. In contrast, using less traditional teaching methods has been shown to relate to better awareness in an earlier study (Yang et al., 2013). We can discuss that curriculum-based assumptions might be more common among teachers who use teacher-centred methods; as the curriculum expects primary school children to reach a relatively high level of understanding, it is easy to overestimate students when compared to these standards. Overall, teachers might also use other child-centred methods that we did not include in our study; thus, further research in this field is certainly needed to better describe relationships between teachers' practices and predictions about students' performance, which is an essential research topic when describing learning and teaching.

Some limitations of our study should also be mentioned. First, we studied teachers and children separately; thus, it is possible that children whom participating teachers teach have different ideas. This format enabled us to examine general predictions, and our results were mainly concordant with earlier studies. Second, we did not ask about teachers' knowledge and thus we do not know if teachers themselves might have had some misconceptions. Third, we used self-report questionnaires to assess teachers' use of different methods. Self-report questionnaires might not adequately reflect teachers' real behaviour; additional research, using different methods to assess teachers' practices, should be conducted before making overall predictions and more precise conclusions. Our results might also be affected by the size of our sample; studies with bigger samples should be conducted to draw overall conclusions.

Understanding constructivism means adopting the idea that children in the same class may have different misconceptions and that learning new material might also promote the rise of new misunderstandings (Duit et al., 2008; Maskiewicz & Lineback, 2013). Overall, our study proved that children in all grades gave a variety of alternative explanations that were constructed by combining new knowledge with previous understanding. In order to better support learning, teachers should understand the process of construction and reconstruction of knowledge. We also agree with the idea that misconceptions should be used as foundations of teaching new concepts (Strauss, 1993). Our study also showed that teachers tend to overrate more fourth- and sixth-grade students' understanding and underrate second-grade students' understanding. Therefore, spending time in all classes and every grade to discuss about what every student thinks about different phenomena is crucial to ensure that learning really happens. LP theory suggests different amendments that should also be made when designing school curriculum that supports more meaningful learning (Smith et al., 2004).

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