【不可使用計算機】＊作答前請先核對試題、答案卷(試卷)與准考證之所組別與考科是否相符！！

一、孔恩(Thomas S. Kuhn)在「科學革命的結構」一書中提出了「典範」(paradigm)和「不可共量性」(incommensurability)的概念，用以解釋科學革命（或發展）的歷程。

1. 何謂「典範」？(5%)
2. 何謂「不可共量性」？ (5%)
3. 請依據你的學科背景（物理、化學、生物、地科等）舉一個科學史的例子說明以上概念如何解釋科學發展的歷程。(10%)

二、問題解決能力是新課綱所欲培養的核心素養之一。

1. 請解釋什麼是「問題解決」 (problem-solving)？ 並請說明 「結構性問題解決 (structured problem-solving) 」和「弱結構性問題解決 (ill-structured problem-solving) 」有何相同和不同之處。(10%)
2. 請以科教的相關理論解釋：提供學生「弱結構性問題解決」的經驗，對科學學習有何影響？ 請依據你的學科背景(物理、化學、生物、地科等)舉一個實例說明。(10%)

三、培養具備科學素養的未來公民，是世界各國科學教育的重要目標。具有科學素養的人，具備參與科學相關事務的能力，其中之一是科學舉證，也就是能解讀科學數據及舉證科學證據的能力。請問：

1. 具備「科學舉證」能力，對培育學生解決日常生活問題及在未來參與公眾決策有何重要性?請舉一個實例說明。(7%)
2. 請依據你的學科專長(物理、化學、生物、地科等)，設計一個具體的教學活動來培養學生的「科學舉證」能力。(13%)

四、擴增實境(Augmented Reality, AR)的技術近年來發展快速，使用者可以透過顯示器在視覺感官上看到虛擬圖像與真實世界兩者結合（例如：Pokemon 寶可夢）。現在有愈來愈多的科學教師及科教學者嘗試利用擴增實境輔助科學的學習。

1. 請闡述並舉例說明運用擴增實境於學生科學學習的可能性（如：擴增實境有什麼優缺點，可以如何運用，有何限制等）。(10%)
2. 擴增實境融入科學學習需以科學學習理論為基礎，才能幫助學生有效學習。請依據你的學科背景（物理、化學、生物、地科等）舉一個科學單元為例，說明你會如何運用擴增實境於此單元，並闡述你所根據的科學學習理論為何。 (10%)

五、請依據下面研究報告回答下列問題：(5% for each; 20% total)

1. 該研究的目的為何？
2. 該研究資料收集的方法與過程（研究設計）為何？
3. 該研究的主要發現為何？
4. 該研究對科學的教學與學習啟示為何？

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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

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

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 ($p < .05$).

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.

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

Study 2

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.

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 overrated students answering to questions about rainfall (more than 70% of teachers 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).

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.

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 $H(2) = 74.63$, $p < .001$.

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.

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 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.

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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.

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.

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).