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Can an Interactive Learning Path on A Tablet PC Counter Misconceptions on the Formation of Clouds and Wind?

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Abstract

It is well-known that misconceptions exist on a range of topics. The origin of these misconceptions can be very different, but some of them can be understood by students struggling with the application of physics concepts in real life situations or in the context of another school subject, e.g. geography. In this paper, different strategies to tackle misconceptions concerning the formation of clouds and wind were studied. In Flanders, this topic is studied in geography at the end of secondary education, but underlying physics principles are taught in the preceding physics courses in the middle of secondary school. Three different strategies to teach the topic in geography were designed and compared: a traditional, teacher centered lecture, a lecture including an experiment showing the process of cloud and wind formation and a lecture in which the students worked through the material themselves by means of an interactive learning path on

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a tablet pc and in which the experiment was included in a movie. In all lectures, explicit reference was made to the underlying physical concepts. In a pretest-posttest quasi-experimental design, the impact of the three formats on the students' conceptual understanding was studied. Results show that the learning outcomes of students in the tablet pc class are not as good as those in the other two conditions. Teaching method, but also learning material and attitude of students, can explain these differences.

Keywords

Misconceptions , Wind , Clouds , Teaching , Tablet PC , Experiment

In general, many people have misconceptions. These misconceptions are persistent and especially in education, teachers should pay attention to the mental models of their students in order to change them into correct scientific ideas (Herman, Feldman & Vernaza-Hernandez, 2017). Traditional education is not always successful in changing these incorrect models into scientifically correct ideas (Hake, 1998; Harrisson, Grayson & Treagust, 1999), but a variety of more effective methods is available (Miller & Brewer, 2010). The basic condition is to start from the prior knowledge of students, and to activate students in their learning process in order to confront them with their scientifically incorrect ideas.

Also in the domain of geography, misconceptions have been described (e.g. Brewer, 2008; Choi, Niyogi, Shepardson & Charusombat, 2010; Nelson, Aron & Francek, 1992). Apart from these domain-specific misconceptions, misconceptions from other natural sciences arise in geography as geography often uses concepts of these natural sciences. In Flanders, Belgium, for instance, the geography curriculum that is compulsory for all students until 18 years old, prescribes subjects in the last two years of secondary education like the atmosphere, geology, or cosmography. In these topics, concepts from physics (optics, heat and energy, magnetism), chemistry (ionisation), or biology (photosynthesis) are included. In the Flemish curriculum, some of these concepts are introduced in the third and fourth year of secondary education, while geography uses them with some delay in the final years. This is a form of transfer as the learning gained in one context or topic, is used in another, and demands for the deployment of prior knowledge (Martin & Schwartz, 2013). As spontaneous, self-directed transfer across different domains and contexts is infrequent (Detterman, 1993), the role of a teacher seems to be important.

One example where physics concepts show up in geography is discussed in this paper, namely the use of the concepts of condensation/evaporation and heat conduction in the class on the atmosphere, and more specifically on the formation of clouds and wind. From previous research it is known that students are often familiar with words, such as temperature, heat, and energy, but that they do not always understand the correct scientific concept behind these words (Chiou & Anderson, 2010; Erickson, 1979; Erickson & Tiberghien, 1985; Harrison et al., 1999). Moreover, research shows that students have difficulties to apply the concepts in everyday contexts (Chu, Treagust, Yeo, & Zadnik, 2012). Therefore, it can be questioned to what extent students are able to use these concepts in other domains such as geography, especially because textbooks often do not explicitly refer to them.

Previous studies have already shown difficulties students have to explain the formation of clouds and wind, sometimes in relation to physics (Henriques, 2002, Rappaport, 2009). Rappaport (2009) mentioned the difficulty to distinguish the gaseous phase and the liquid phase of water, and that students consequently wrongly think that water vapour is sometimes visible. They therefore see clouds as a mixture of droplets and water vapour. Students also think that a water reservoir is necessary for condensation to occur. Students have thus a limited insight in the transport of water vapour throughout the atmosphere. Henriques (2002) mentioned e.g. that students think that warm air weighs more than cold air, whereas the density, volume and pressure are important parameters to study.

Apart from the occurrence of misconceptions, also the role of experiments in classes is studied. Pizzolato, Fazio & Battaglia (2014) pointed at the importance to use experiments in the classroom to gain insight in learning concepts and outcomes. Similarly, Siler, Klahr & Matlen (2013) pointed at the fact that experiments can involve conceptual learning, besides procedural learning. However, research in physics education suggests that traditional demonstration experiments may not effectively help students to grasp the underlying scientific concepts or recognize and change scientific misconceptions they have. Also for demonstration experiments active engagement of students enhances the learning effect (Crouch, Fagen, Callan & Mazur, 2004; Miller, Lasry, Chu & Mazur, 2013; Roth, Campbell, Keith & Boutonne, 1997). While in physics classes experiments are often used, as a demonstration tool by the teacher or as an activating tool for students, experiments in geography classes are rare. The most important reason for this is the time constraint. Nevertheless, experiments in classroom can demonstrate the formation of clouds and wind (NASA, 2017).

As conceptual change is an individual process that can only be stimulated by activating students (Duit & Treagust, 1998), and as technological solutions offer possibilities for students to work independently, the use of a tablet pc has potential in this context. Some studies already questioned the use of tablet pc's in scientific classes or fieldtrips (Fisher, Cornwell, & Williams, 2007; Guelman, De Leone, & Price, 2009; Knoop & van der Pluijm, 2006), and some showed a positive effect of this learning material on the learning outcomes of students (Derting & Cox, 2008; Schneps, Ruel, Sonnert, Dussault, Griffin & Sadler, 2014), but many of these studies looked at their use in (undergraduate) university courses, and not in secondary education. Moreover, many authors chose to measure their use qualitatively, and not quantitatively.

Based on the research findings described in literature and on the curriculum in Belgium, the aim of this research is to explore students' conceptions and learning about cloud and wind formation in different (geography) lecture conditions, all with an explicit reference to related physics concepts: a traditional lecture based format, a lecture in which real experiments illustrating the phenomena were incorporated, and a lesson where students worked in pairs through the material by completing activities that were structured in a learning path on a tablet pc. Our hypothesis is that an experimental setup in a geography class has a positive effect on the use of these physical concepts in geography, and therefore that less misconceptions are observed with the students. The use of a tablet pc with a filmed experiment is hypothesized to have the same effect as the demonstration of the experiment in the classroom.

Methodology

Educational Context

The study we describe was carried out in secondary education in Flanders in the context of a geography course. Geography is a compulsory subject with a detailed mandatory curriculum. One of the topics deals with weather and climate and the attainment goals ask students 'to relate weather and climate to the structure of and the processes within the atmosphere' (ET 6 of the Flemish curriculum for geography in the 3th grade (5th and 6th year) of secondary schools). For this study, this broad theme was narrowed and the content of the lectures to which the study relates was guided by the following questions: What are clouds made of and how are they formed? Why do clouds form high in the troposphere? What is wind? What causes wind?

Answering these questions requires the understanding of the underlying physical concepts of evaporation and condensation, gas laws, Archimedes' principle … These concepts are subject of the (mandatory) physics course that students take in their 4th year of secondary education.

Participants

341 students from 21 classes in 6 schools in Flanders participated in the study. All students were in their 5th or 6th year of secondary education (aged 16-18), some having a focus on sciences in their school program, others a focus on (classical) languages and also some having a more technically oriented program. The students had not previously been taught about cloud formation and wind. In total, 6 geography teachers were involved in the study. The teachers were known by the researchers because of their participation in teacher training programs, and were asked by the researchers to participate in the project.

Experimental conditions

Three different lecture conditions were designed, all with an explicit reference to related physics concepts: a traditional lecture based format, a lecture in which real experiments illustrating the phenomena were incorporated and a lecture where students worked in pairs through the material by completing activities that were structured in a learning path on a tablet pc. Every lesson lasted for 50 minutes, and had a clear time schedule, guaranteeing that the content could be teached within this time frame. The detailed design as developed by the researchers assured the reliability of the study,

Classes were randomly assigned by the researchers to one of the three conditions, mainly led by practical reasons (e.g. amount of students in each condition, tablet pc lessons in one week). All lessons were given in the school of the students and by one of the authors (F.H.). The teacher of the class observed the lecture.

Traditional lecture. Here, the processes of cloud and wind formation were taught in a 'traditional' way: the teacher guided and structured the lecture period by asking questions and building the content together with the students. A detailed lesson plan was prepared and followed to ensure that both the structure and the content of all traditional lectures were comparable over the different classes. A PowerPoint presentation with clear figures was used to illustrate the concepts. In total 100 students (53 boys and 47 girls) out of 6 classes followed the traditional lecture.

Experiment based lecture. In this condition, lectures are structured around real experiments. To visualize the process of cloud formation and occurrence of wind, two experiments showing these phenomena were developed. In the first experiment, the condensation of water vapor on nuclei, formed by striking a match, was shown in order to explain that clouds consist of water droplets. In the second experiment, the circulation of clouds between areas of high and low pressure was shown by striking a match in a glass bowl filled with ice cubes on the one side and with relatively hot sand on the other side (37°C).

In these lectures, the content was developed starting from (questions about) the experiments. Again, all the lectures were taught by the same researcher with the same material, following a detailed lesson plan to make all lectures comparable. The figures used were the same as those in the traditional lecture. 116 students (60 boys, 51 girls and 5 unknown) from 8 classes attended this experiment based lecture.

Tablet pc based lecture. The third lesson format was not lecture based. In this condition, students worked in pairs through a series of activities that were structured in a learning path on a tablet pc. More specifically, an iBook for iPad (Apple) was developed containing concept cartoons, video material on the experiments, and student questions to get insight in the process and background information. Again the same figures as the ones used in the traditional and the experiment based lecture were used. Students were not trained in self-regulated learning before the lesson.

Every two students had one tablet pc. After a short introduction on the goal of the experiment (students were not used to the use of a tablet pc in a geography lecture), students completed the activities on their own tempo while two researchers walked around to provide technical help if needed. There was no whole group activity. 125 students (57 boys, 67 girls and 1 unknown) from 7 classes followed this learning path on the tablet pc.

Questionnaires

To measure student learning in the different conditions, three questionnaires were developed. Students were asked to fill in these at different times: one at the start of one of the lessons described above (the pretest), one at the end of this lesson (the posttest), and one a few weeks after the lesson (the retention test). The questionnaires were partly overlapping and partly different from each other. All the questions can be found in the appendix. Also a questionnare on the student experiences was developed. Also the teachers were asked to complete a questionnaire at the end of the lesson.

Development and content of questionnaires on scientific concepts. The items in the student questionnaires related to the formation of clouds and wind. The questions focus on student misconceptions as they are known from literature

(Rappaport, 2009; Henriques, 2002). All questions are formulated as multiple choice questions with the known student ideas as alternatives. In total eight items were developed. In order to assure the validity of the tests, their content and formulation was discussed with an expert in climatology. She critically judged the formulation of the items and assured that there exists no doubt about the suggested alternatives.

A first question deals with the meaning of the term 'water vapor'. Following Henriques (2002), it seems that many students have no clear idea of what water vapor is. Also Rappaport (2009) mentions that there is confusion between water in the gaseous and liquid phase, and that a misconception is that water in its vaporous state is sometimes visible to the eye. As a consequence, it is unclear to students when a phase transition occurs. Students do talk about 'saturation' to explain that vapor becomes visible but they do not necessarily link this to a phase transition.

As a second consequence, students do not exactly know what clouds are made off and many students believe that clouds consist of water vapor, thus ignoring the gas-to-liquid phase change (Rappaport, 2009, Henriques, 2002). This misconception is reinforced by the observations children make when using an electric kettle: the gas escapes from the boiling water, condenses in the air above and forms droplets, but this latter process is ignored by the children (Henriques, 2002). Therefore, the second question in the questionnaire asks for the composition of clouds.

The third and fourth question deal with cloud formation. Several difficulties are summarized in both: the processes of condensation and evaporation are questioned again (alternative 3a, 3c, 3d, 3e, 4a, 4b, 4c), but also the difference between air and water vapor is incorporated (alternative 3a, 3c, 4c). Moreover, many students think that water evaporates only from large water basins like lakes or oceans (alternative 3b), an image that is often created in textbooks when illustrating the water cycle (Henriques, 2002). Finally, question four also probes for the lack of understanding mentioned by Rappaport (2009) where he states that none of his interviewed students explained that water in an air mass can re-evaporate when it descends and becomes warmer, and for students' ideas on humid air and hot air (hot air weighs less than cold air) (Henriques, 2002).

Question 5 probes whether students understand why clouds are often seen in the troposphere, while question 6 asks for student ideas on wind. Young children think that wind originates from moving trees, clouds or because the earth rotates (Boersma, van Graft & Knippels, 2009). Nelson et al. (1992) report that students believe that air in motion always obeys the pressure gradient force, and flows from high to low pressure, whereas this is only true for surface winds.

In the posttest and retention test two questions were added to measure students' ability to transfer knowledge to situations that are not explicitly dealt with in class. Question 7 is about the formation of fog near the surface as Rappaport (2009) indicates that students do not always realize that fog can arise by cooling moist air. They often think that fog is formed by evaporation above a water surface. Item 8 relates the position of high and low pressure areas to their place on earth and to the motion of air in a vertical air column. As students are often confused about the movement of air near the surface and higher in the troposphere (Henriques, 2002), it is clearly mentioned that wind near the surface is meant. This combination of rather superfical elements and more profound understanding lead to the development of conceptual understanding according to Hattie (2012).

Student expericence. The content based questions were accompanied by some questions in the pretest concerning the gender of the participants, their year of birth, their current and previous education, and their motivation for physics. In the posttest, students formulated their ideas about the lesson format. On a five point Likert scale, they indicated whether they enjoyed the lesson, how innovative the lesson was, how clear it was and whether they could keep their attention to the lesson. They were also asked to estimate their ability to remember the lesson content after the lecture.

Teacher ideas. After the lessons, teachers completed an online survey on the lecture they observed. This survey consisted mainly of open questions, but also some multiple choice questions were included. Teacher appreciation on the explicit relation between the content of the geography and physics lectures was questioned, as well as whether this was more explicit in this lecture compared to their own lessons. If positive, their motivation to repeat this for their own lectures in the next years was gauged. For the experiment based lesson, the added value of the experiment in relation to the weather theme of the lecture was asked and their willingness to use the experiments in the next years, albeit as a live experiment in the class, or as a film fragment. Finally, we asked for their experience with the use of a tablet pc in this lecture: did they experience an added value compared to a traditional lesson? Would they consider an extension of this kind of learning paths to other geography lessons? Five teachers out of six completed the survey.

Method of Analysis

Based on student answers on the multiple choice items, and taking into account the different alternatives, different scores were defined and computed.

Global test score. A global test score (for the items that are common to all three tests, i.e. items 1-6) is defined as the sum of the item scores, where the item score is calculated by adding

+1 if a correct alternative is indicated,
-1 if an incorrect alternative is indicated,
0 if no alternative is indicated.

Remark that this definition implies that an item score can be greater than 1 or smaller than -1. The global test score can range between -15 and 9.

Paired sample t-tests were run to find out whether scores improved in the different conditions. A one-way ANCOVA was conducted to determine a statistically significant difference between the lecture types on the gain scores (post-pre/retention-pre) controlling for pretest results.

Misconception scores. Apart from the global test score, we are interested in the (dis)appearance of the different misconceptions. Therefore, different misconception and their prevalence are discussed for the different conditions.

Teacher perceptions are measured using Likert scale items. Although these data are available, we decided not to use them in this paper quantitavely, but only to report some of the trends qualitatively.

Findings

In this section, we start with the global test score results and then proceed to the different misconceptions. Thirdly, we describe whether students could transfer the concepts from lecture to a new context. At the end the teachers' perceptions on the different conditions are summarized.

Global Test Score

A global test score was computed for each student, based on items 1-6 in the pre-, post- and retention test. The results of the global test scores in the different conditions are shown in Table 1. Paired sample t-tests indicated that scores were significantly higher for the post- and retention test than for the pretest in all conditions. Results are in Table 2.

Table 1
Global Test Scores for the Different Conditions for the Pretest, Posttest and Retention Test

Type of lecture	Mean pretest (SD)	Mean posttest (SD)	Mean retention test (SD)
Traditional (n=96)	1.01 (2.74)	4.76 (1.83)	4.25 (2.48)
Experiment (n=95)	0.84 (2.72)	4.42 (2.10)	3.74 (2.58)
Tablet (n=119)	1.03 (2.78)	3.92 (2.09)	3.41 (2.31)

Table 2
Data on the Paired Sample T-Tests to Compare Different Test Scores

	M	SD	t	df	Sig. (2-tailed)
Traditional Pre-post	-3.75	2.44	-15.05	95	0.000
Traditional Pre-retention	-3.24	3.33	-9.53	95	0.000
Experiment Pre-post	-3.58	2.83	-12.31	94	0.000
Experiment Pre-retention	-2.90	3.45	-8.17	94	0.000
Tablet Pre-post	-2.89	2.92	-10.78	118	0.000
Tablet Pre-retention	-2.38	3.59	-7.23	118	0.000

A one-way ANCOVA was conducted to determine a statistically significant difference between the lecture types on the gain scores (post-pre) controlling for pretest results ($F(2,306) = 5,599$, $p=0,004$).

Post-hoc analysis indicated that the learning effect as measured by the gain scores was lower for the tablet lecture than for the lecture with experiments ($p=0,035$) and lower than for the traditional lecture ($p=0,001$). Results between the traditional lecture and the lecture with experiments were not significantly different ($p=0,280$).

A similar ANCOVA analysis for the retention test showed similar results (F (2,306) = 3,171, p=0,043). Post-hoc analysis showed that the difference between tablet and experiment lecture disappeared (p=0,305), while the tablet lecture remained different from the traditional lecture (p=0,012). Results between the traditional lecture and the lecture with experiments again were not different (p=0,160).

Misconception Scores

As we also want to gain insight in the (dis)appearance of the different misconceptions, misconceptions are discussed and their "evolution" is compared over the different conditions. Because we are mainly interested in trends and we do not want to overload the text by reporting on statistical tests, we present frequencies of different student ideas and discuss them without statistically testing all different aspects.

Water vapor. As mentioned earlier, many students have no clear idea of what water vapor exactly is, and are confused on what clouds are made of (Henriques, 2002). Table 3 shows the fractions of correct answers on the first question of the test (correct means only alternative 'a' is picked).

Table 3
Fraction of Students Answering Correctly That Water Vapor is Water in the Gaseous Phase

Type of lecture	Fraction correct Pretest	Fraction correct Posttest	Fraction correct Retention test
Traditional (n=96)	0.72	0.80	0.81
Experiment (n=95)	0.79	1	0.91
Tablet (n=119)	0.71	1	0.76

The table shows that students correctly understand what water vapor is, but still between 10-25% of students does not have the correct idea after instruction. The fraction of students that does well on the retention test in the experiment lecture is significantly higher than in the tablet condition (p<0,001).

As some authors mention that some students think of water vapor as a phase between liquid and gas (Rappaport, 2009), we included that possibility as an alternative. Table 4 gives the fraction of students that picked alternative'd' in Question 1, possibly in combination with other distractors.

Table 4
Fraction of Students Including 'Water Vapor Is a Phase between Gas and Liquid' In Their Answer

Type of lecture	Fraction gas-liquid Pretest	Fraction gas-liquid Posttest	Fraction gas-liquid Retention test
Traditional (n=96)	0.26	0.04	0.13
Experiment (n=95)	0.20	0.01	0.05
Tablet (n=119)	0.27	0.11	0.17

We see that the misconception also shows up in our population in the pretest but seems to be reduced in all lecture formats. The misconception occurs significantly less in the experimental lecture than in the other formats (retention test, $p<0.001$).

Composition of clouds. Related to the water vapor misconception, Rappaport (2009) and Henriques (2002) report that students do not exactly know what clouds are made of. We therefore included an item explicitly testing this. Table 5 shows the fraction of students that answered the question correctly, i.e. picked alternatives 'b' and 'c'. Table 6 shows the fraction of students that only picked the water droplet alternative ('b'). Table 7 shows how many students chose at least 'water vapor' as an alternative ('a').

From Table 5 it is clear that only a few students answer Question 2 correctly, and that correct answers tend to be forgotten again in the retention test. This can be partially understood by looking at answers that only mention water droplets and not ice crystals: the numbers increase (Table 6) but show that most students include more of the alternatives. Table 7 adds to that in the sense that both in the pretest and the retention test, a significant fraction of students includes 'water vapor' in their answer.

Table 5

Fraction of Students That Correctly Answered That Clouds Are Made of Water Droplets and Ice Crystals

Type of lecture	Fraction correct Pretest	Fraction correct Posttest	Fraction correct Retention test
Traditional (n=96)	0.03	0.30	0.03
Experiment (n=95)	0.01	0.19	0.08
Tablet (n=119)	0	0	0.02

Table 6

Fraction of Students Only Answering 'Water Droplets'

Type of lecture	'water droplets' Pretest	'water droplets' Posttest	'water droplets' Retention test
Traditional (n=96)	0.06	0.56	0.50
Experiment (n=95)	0.11	0.60	0.32
Tablet (n=119)	0.16	0.87	0.61

Table 7

Fraction of Students Including 'Water Vapor' In Their Answer

Type of lecture	'water vapor' Pretest	'water vapor' Posttest	'water vapor' Retention test
Traditional (n=96)	0.73	0.04	0.30
Experiment (n=95)	0.82	0.11	0.50
Tablet (n=119)	0.72	0.07	0.29

Student ideas on the composition of clouds are not only tested in Question 2, but indirectly also in Question 3 and Question 5: alternative 'a' in Question 3 and alternative 'a' in Question 5 both refer to clouds as consisting of water vapor. Table 8 shows the fraction of students that includes alternative 'a' in Question 3, and Table 9 the fraction including alternative ‘a’ in Question 5. From these tables, we see that in these implicit questions, the prevalence of the idea that clouds consist of water vapor is much smaller than when probed explicitly and reduces after instruction.

Table 8

Fraction of Students Including Alternative A in Their Answer to Question 3

Type of lecture	‘water vapor’ in Q3 Pretest	‘water vapor’ in Q3 Posttest	‘water vapor’ in Q3 Retention test
Traditional (n=96)	0.26	0.09	0.13
Experiment (n=95)	0.23	0.13	0.12
Tablet (n=119)	0.25	0.14	0.13

Table 9

Fraction of Students Including Alternative Q in Their Answer to Question 5

Type of lecture	‘water vapor’ in Q5 Pretest	‘water vapor’ in Q5 Posttest	‘water vapor’ in Q5 Retention test
Traditional (n=96)	0.23	0.07	0.05
Experiment (n=95)	0.17	0.07	0.09
Tablet (n=119)	0.29	0.12	0.05

Cloud formation. Students that correctly understand the mechanism of cloud formation should answer alternatives ‘c’ and‘d’ in Question 3 and alternative ‘c’ in Question 5. Table 10 shows the fraction of students that correctly pick these alternatives.

Table 10

Fraction of Students That Pick the Correct Alternatives on Cloud Formation

Type of lecture	Fraction correct Pretest	Fraction correct Posttest	Fraction correct Retention test
Traditional (n=96)	0.06	0.26	0.25
Experiment (n=95)	0.08	0.28	0.22
Tablet (n=119)	0.05	0.22	0.13

Although the number of students ticking the correct answers increases, the fraction of correct answers is small and indicates that in none of the conditions, students get the precise idea. When including also other (incorrect) alternatives, the number raises but these students have a mixture of correct and incorrect ideas.

Many students think that clouds only origin above ‘large water basins’ (Henriques, 2002). Table 11 shows the fraction of students that show this idea by ticking the answer ‘clouds always arise above a water body’. We see that this idea also is very strongly present in our students’ heads and, although it decreases in the posttest, remains fairly strong in the retention test.

Table 11

Fraction of Students Showing the Idea That Clouds Only Origin above 'Large Water Basins'

Type of lecture	'large basins' Pretest	'large basins' Posttest	'large basins' Retention test
Traditional (n=96)	0.61	0.21	0.41
Experiment (n=95)	0.60	0.29	0.42
Tablet (n=119)	0.61	0.39	0.48

Wind. The last common question deals with wind. In this question we probe for student understanding of the concept of and mechanism explaining wind. Only few students answer that wind is caused by the rotation of the earth or by clouds. The fraction of students that think wind is caused by a temperature difference is shown in Table 12. Table 13 shows the fraction of students mentioning pressure difference as cause, while Table 14 shows the fraction of students choosing both alternatives.

These figures show that quite a number of students already enter the lecture with a correct understanding of the cause of wind, and that this number does not really increase in the retention test. It is striking that the results are better in the retention test than in the posttest. However, after the intervention, the regular lessons on weather and climate continued in the classroom and according to the curriculum, students practiced to read weather maps and to predict weather conditions on different places. These concepts about wind in relation to temperature and air pressure are then further discussed and used in geography classes.

Table 12

Fraction of Students That Think That Wind Is Caused By a Difference in Temperature

Type of lecture	$\Delta T \rightarrow$ wind Pretest	$\Delta T \rightarrow$ wind Posttest	$\Delta T \rightarrow$ wind Retention test
Traditional (n=96)	0.07	0.03	0.03
Experiment (n=95)	0.06	0.05	0.02
Tablet (n=119)	0.08	0.08	0.04

Table 13

Fraction of Students That Think That Wind Is Caused By a Difference in Air Pressure

Type of lecture	$\Delta p \rightarrow$ wind Pretest	$\Delta p \rightarrow$ wind Posttest	$\Delta p \rightarrow$ wind Retention test
Traditional (n=96)	0.61	0.55	0.74
Experiment (n=95)	0.60	0.42	0.66
Tablet (n=119)	0.63	0.51	0.62

Table 14

Fraction of Students That Think That Wind Is Caused By a Difference in Temperature and Air Pressure

Type of lecture	$\Delta T + \Delta p \rightarrow$ wind Pretest	$\Delta T + \Delta p \rightarrow$ wind Posttest	$\Delta T + \Delta p \rightarrow$ wind Retention test

Traditional (n=96)	0.19	0.34	0.16
Experiment (n=95)	0.16	0.44	0.17
Tablet (n=119)	0.13	0.32	0.22

Transfer Questions

Besides getting inside in student understanding of concepts explicitly dealt with in lecture, we also wanted to see whether students can apply the ideas in different settings. We consider the question on the disappearance of clouds (Question 4) as a transfer question, but we also included two extra questions in the posttest and the retention test meant to measure transfer.

In the question on disappearance of clouds, we check whether students got the idea that when the temperature rises, the water can re-evaporate and so the cloud disappears. Table 15 shows the fraction of correct answers in the different conditions.

The table shows that about half of the students answers the question already correct in the pretest and not many more do it correct in the retention test. The posttest results are worse than the pretest scores, but in the retention test student answers are better.

Table 15

Fraction of Students Answering Correctly On the Questions Concerning the Disappearance of Clouds

Type of lecture	Fraction correct Pretest	Fraction correct Posttest	Fraction correct Retention test
Traditional (n=96)	0.55	0.34	0.60
Experiment (n=95)	0.42	0.44	0.59
Tablet (n=119)	0.51	0.32	0.54

Besides the question in the first part of the questionnaire, also two transfer questions were added in the post- and retention test. A first one deals with fog as a cloud, and measures whether students realize that fog can form by cooling moist air (condensation) and not only by evaporation above a water surface. The question is designed as a coupled multiple choice question where students have to combine different aspects. Table 16 shows the fraction of students that answer the question completely correct in the different conditions. It is clear that we got bad results in the posttest. In the posttest, students in the traditional and experimental condition do better than students in the tablet condition. This remains the same in the retention test.

Table 16

Fraction of Students Answering Correctly On the Transfer Questions on Fog

Type of lecture	Fraction correct Posttest	Fraction correct Retention test
Traditional (n=96)	0.30	0.33
Experiment (n=95)	0.27	0.34
Tablet (n=119)	0.17	0.19

The second transfer question probes for student understanding of occurrence of high and low pressure areas and the relation with wind. Table 17 shows fractions of correct answers. Again, the results are bad. Students in the traditional lecture do better than students in the lesson with experiment in the posttest. In the retention test, students in traditional and experimental condition do better than students in tablet condition. Results improve in the retention test.

Table 17

Fraction of Students Answering Correctly On the Transfer Questions on the Relation between Wind Ad Air Pressure

Type of lecture	Fraction correct Posttest	Fraction correct Retention test
Traditional (n=96)	0.40	0.57
Experiment (n=95)	0.26	0.64
Tablet (n=119)	0.28	0.36

Student Ideas about the Tablet pc Based Lesson

Although students were positive about the innovative character of the tablet pc based lesson (4.02 on 5), they also indicated that it was difficult to hold attention to this lesson and that they probably won't remember the learning content for a long time. This was explained by the structure of this lesson, and in contrast with the fact that they realise that the experiments illustrate the lerarning content (4.29 on 5) and that the excercices obliged them to think (3.38 on 5). Out of the three types of lessons, the lesson with the experiment is the most positively evaluated.

Teacher Ideas about the Use of Tablet pc's

Five teachers out of six filled in the online questionnaire. Four teachers were rather positive on the use of tablet pc's in the classroom, one was negative, although the latter would still use a tablet pc in the classroom with another educational approach.

Positive elements on the use of the tablet pc's were the fact that students had to work individually or in pairs, and that they were more involved by thinking actively on the content. This was reinforced by the fact that the students were motivated by the use of the tablet pc. The presence of a lot of questions in the learning path was positively evaluated, especially because of the feedback on the questions.

Teachers were negative on the following issues: the lack of a recapitulation or an evaluation moment was mentioned by 4 out of 5 teachers. Also the fact that students didn't make notes was negatively experienced. Furthermore, working in pairs was difficult according to the teachers. It was also mentioned that the students ran too quickly through the learning path and that they reflected too little on the wrong answers.

Concerning the use of a filmed experiment in the learning path the teachers were all positive. All teachers would use the film in their usual lessons because it explains the course material, gives extra insight, it saves time and the students were attentive. They also think that students remember the lesson content longer after seeing the experiment. Especially for large class groups the experiment on film is seen as a solution; teachers think that students in small class groups could conduct the experiment themselves, especially in small research projects. There were also some constraints on the use of the real experiment in the classroom that are related to the infrastructure of the school or classroom and to the fear of teachers that the experiment could fail in the class.

Discussion

Bringing all the results together, it is clear that students improved their results on the test on the formation of clouds and wind after following one of the developed lectures. This improvement is slightly lower for the retention test than for the posttest, as was expected. However, in general, the scores on the test were rather low, and differences between the different lectures are observed. The global test score results showed that students in the traditional condition performed best on the test, while results in the tablet condition were less good. Also, when studying the individual misconceptions probed in the test, many misconceptions remained present, especially within the lecture with the tablet pc. Both the fact that misconceptions not really disappeared and the lower scores in the tablet pc lecture, will be further discussed.

The high prevalence of the different misconceptions, shows again that misconceptions are very robust, even tough the physics principles underneath are explicitly targeted in all lectures. This is comparable to findings of Duit & Treagust (1998), and to those of Harrison et al. (1999) who described changing concepts of heat and temperature not to be revolutionary, but rather time consuming. Furthermore, the presence of these misconceptions prohibit students to come to deep understanding and to apply knowledge to new situations. Indeed, from the questionnaire it was clear that questions on the ice crystals in clouds, on the disappearance of clouds in situation where temperature raises, or on the presence of fog, were poorly answered. The expected positive effect of the use of an experiment was also less than hoped for. Both in the experimental and in the tablet pc lecture, experiments on the formation of clouds and wind were shown, in front of the classroom in the one condition, and on video in the tablet condition. In both experiments, clouds were formed by evaporation of warm water and then making this water to condensate. Evaporation was induced by placing a plate with hot water in a basin. However, this experimental setup strengthened for some students the misconception that clouds always arise above a water surface on the one hand and that wind is caused by a temperature difference on the other hand as the results in Table 11 show: the fraction of students who hold this misconception is higher in the experimental and tablet condition than in the traditional lesson. Therefore, when using experiments all aspects and details of the experiments should be carefully studied as they may cause side effects, although students and teachers appreciated the use of the experiments very much (Crouch et al., 2004; Miller et al., 2013; Roth et al., 1997).

The results that show that the lecture with the tablet pc's is less succesfull in changing the mental model of students can be studied as well. This observation was rather unexpected because our objective with the tablet pc was to actively engage students with the lesson content in order to have them to better understand the concepts taught. Moreover, the motivation of students to use a tablet pc in class was very high. We think the worse results for the tablet pc lecture can be attributed to two elements.

First, students could discuss the multiple choice questions in the learning path in pairs. Some pairs of students tried to do this very accurately, but some pairs very superficially. Discussions are however very important in changing the mental model of a student (Minstrell & Smith, 1983). Students who just push on the different alternatives in multiple choice questions until the green colour of the correct bullet appears, miss an understanding of the concept behind the correct solution as all the explanations behind incorrect answers, are not studied. Many of these students also ended their trajectory throughout the learning path far before the end of the foreseen time, an indication of this superficiality. This suggests that students should be prepared to self-regulate their learning, and that teachers should support their students to do that. This is related to the findings of Hattie (2012), who supports the idea of preparing teachers to train how to use computers as a learning a teaching tool, and who also supports the idea to train the self-regulation of students. Secondly, the development of the learning path on the tablet pc might have been better structurerd. As it was developed, students followed one linear traject troughout the lesson and didn't take notes. However, more structure in the learning material, and even an extra worksheet on paper, might have forced them to think more actively and to express scientific explanations.

In this paper we do not want to pleed for skipping all lessons with a tablet pc from geography classes. Although the results show that students have better results after following the traditional lesson, we are aware of the fact that the teacher in front of the classroom was one of the researchers, thus someone who is trained in dealing with misconceptions. Indeed, teachers' awareness on student ideas is important in changing their students' mental models, and we found it was striking from the questionaires that the strong emphasis on the misconceptions and the expliciet reference to the physics concepts that was put in the lessons by the researchers, was never mentioned as a positive element by the observing teachers. It is also clear that teachers were not conscious of the possible misconceptions that the experiments reinforced in the students minds. Earlier research in Belgium has already proven this lack of awarenees in relation to another topic (Cox, Steegen & De Cock, 2016).

Conclusions and Recommendations

The purpose of this study was to evaluate the impact of three different types of lectures on student understanding of cloud and wind formation. Hereby, explicit attention was paid to the underlying physical concepts. In a pretest posttest retention test quasi experimental design, student learning was studied. Only little difference in learning outcomes between the three conditions was observed, and the learning gains were in all conditions rather small. More surprisingly is the fact that learning gains for the tablet pc lecture were smaller than expected. Therefore we recommend to stimulate self-regulated learning and to structure the learning material in another way: in our learning path the material was offered too 'linear'. Moreover, the role of the teachers remains important in pointing at and confronting students with possible difficulties or misconceptions within the learning content. Then, the first condition is, of course, that teachers are aware of these misconceptions before teaching the content. Future research could test these recommendations.

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Biographical statements

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Appendix I. Questions from the pretest, posttest and retention test

1. Water vapor is
   a. water in the gaseous phase
   b. water in the liquid phase
   c. water in the solid phase
   d. a phase between gas and liquid
   e. a phase between gas and solid
2. A cloud consists of:
   a. water vapor
   b. water dropplets
   c. ice crystals
   d. warm air
   e. cold air
3. Which statement(s) about the formation of clouds is / are correct?
   a. Water that evaporates, is seen as a cloud.
   b. Clouds always arise above a water surface (sea, lake, river …). Sometimes they are afterwards (then) blown by the wind over the land surface.
   c. When moist air cools, a cloud can occur.
   d. Clouds are formed by the condensation of water vapor into droplets.

4. A cloud disappears when the temperature rises. True/false

5. Why are clouds often in the troposphere and not only on the ground?

   a. Warm water vapor rises. This water vapor is seen in the form of a cloud in the troposphere.
   b. When water evaporates, it becomes lighter. Therefore, we see a cloud in the troposphere.
   c. Warm air rises. That air cools higher in the troposphere and condenses there into a cloud.

6. Which statement(s) about wind is / are correct?

   a. Wind is the movement (displacement) of air.
   b. Wind is created by the rotation of the earth around the sun.
   c. Clouds cause wind.
   d. A temperature difference between two places causes wind.
   e. A difference in pressure between two places causes wind.

Appendix II. Additional questions for the posttest and retention test

7. In Belgium fog sometimes nicely follows the coastline. Therefore fog is sometimes only hanging over the sea, and sometimes only over land. But how can you explain this? Please circle the correct answer for each choice.

<u>Fog above LAND</u>

Occurs when

1. Warm sea air moves over cold land
2. Cold sea air moves over warm land
3. Warm land air moves over cold sea water
4. Warm land air moves over warm sea water

Because

i. Sea water evaporates and this water vapor forms fog that moves to the land.
ii. Air cools and condenses.
iii. Air warms up and causes water on land to evaporate.

This happens

a. Mainly in summer.
b. Mainly in winter.
c. Throughout the year.

<u>Fog above SEA</u>

Occurs when

1. Warm sea air moves over cold land
2. Cold sea air moves over warm land
3. Warm land air moves over cold sea water
4. Warm land air moves over warm sea water

Because

i. Sea water evaporates and this water vapor forms fog above sea.
ii. Air cools and condenses.

iii. Air warms up and causes water on land to evaporate. This water vapor causes fog that moves to the sea.

This happens

a. Mainly in summer.
b. Mainly in winter.
c. Throughout the year.

8. Choose the correct answer from the possibilities underneath:

In theory (given a uniform and not rotating earth)

<u>At the earth surface near the North Pole</u>

1. An area of high pressure
2. An area of low pressure

Usually occurs because

i. The pressure in a gas decreases when the temperature decreases.
ii. The air cools down, descends and this causes more pressure on the earth surface.
iii. The air cools down, rises and this causes less pressure on the earth surface.
iv. Cold air can contain only few water and therefore has a small mass density. This causes a low air pressure.

<u>At the earth surface near the equator</u>

1. An area of high pressure
2. An area of low pressure

Usually occurs because

i. The pressure in a gas increases when the temperature increases.
ii. The air warms up, rises and this causes less pressure on the earth surface.
iii. The air warms up, descends and this causes more pressure on the earth surface.
iv. Warm air can contain a lot of water and therefore has a high mass density. This causes high pressure.

→ Theoretically the air near the earth surface will therefore move

1. From the North Pole to the equator.
2. From the equator to the North Pole.