The learning effects of combining Peer Instruction with a cognitive conflict strategy

Key words: Cognitive conflict strategy, Peer Instruction and Nature of Science

Abstract

In this quasi-experimental study the learning effects of combining Peer Instruction with a cognitive conflict strategy were investigated. It remains unclear how a cognitive conflict can be optimally implemented in a real classroom. Therefore, this study investigated whether combing the teaching method Peer Instruction with a cognitive conflict strategy has an effect on students' learning gain and views on the Nature of Science. This was investigated with an experimental and control group, where students in the experimental group had a Peer Instruction lesson with a cognitive conflict strategy and students in the control group had a Peer Instruction lesson without a cognitive conflict strategy. The first step of the cognitive conflicted strategy appeared to be successful for some misconceptions. On the other hand, ambiguous questions and asking students to answer from a specific point of view influenced how students voted for the ConcepTest questions. Unfortunately, the learning gain was not higher in the experimental group than in the control group. Semi-structured interviews revealed that some students did not experience a cognitive conflict, because they did not observe that their answer was incorrect. In addition, some students indicated that the contemporary theory was difficult. Furthermore, there were some interesting differences for the Nature of Science issues about: objectivity and subjectivity, validation of scientific knowledge, tentativeness of science and the scientific method.

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1. Introduction and theoretical framework

Confronting students with the consequences of their conceptions can be described as a cognitive conflict strategy (Limón, 2001). This strategy is sometimes successfully implemented in a classroom (e.g. Dreyfus, Jungwirth, & Eliovitch, 1990; Pearsall, Skipper, & Mintzes, 1997). Dreyfus, Jungwirth and Eliovitch (1990) showed that creating a meaningful conflict and providing a meaningful solution had a positive influence on students learning. On the other hand, there are studies which report that the cognitive conflict strategy was not effective at all (e.g. Champagne, Gunstone, & Klopfer, 1985; Limón & Carretero, 1997). According to Limon (2001) the cognitive conflict strategy was not effective due to the different factors in a real classroom setting. There is no golden recipe on how to implement a cognitive conflict strategy (Limón, 2001). Therefore, it remains unknown to what degree a cognitive conflict strategy can be successfully implemented in a real classroom setting (Villani, 1992).

With successfully implementing a cognitive conflict strategy we mean that it leads to conceptual change. Unfortunately, almost every researcher does have its own definition of conceptual change (Limón, 2001). Some researchers argued that students will make a radical shift from the "old" theory to the "new" theory where students reject the "old" theory (i.e. Posner, Strike, Hewson & Gertzog, 1982). Posner and colleagues (1982) assumed that it is more likely that students will reject the "old" theory and replace it by a "new" theory when students experience dissatisfaction with their ideas and when the "new" theory is plausible, intelligible and fruitful. Other researchers argued that students will not radically shift from a theory, but they will use the "old" and "new" theory together (Spada, 1994). Depending on the situation a student will use their naïve or scientific explanations. For example, the idea that a force is required for sustaining constant motion is a very useful idea in daily life, but this idea is incorrect according to the contemporary scientific community (Tao & Gunstone, 1999).

Piaget (1977) argued that a cognitive conflict is a fundamental condition for conceptual change. Therefore, students first need to experience a cognitive conflict before they can make the second step leading to conceptual change. Students who experience a cognitive conflict will not automatically change their schemas, in other words, generating a cognitive conflict does not guarantee conceptual change. According to Piaget (1977) students can react in different ways on a confusing situation. There is a possibility that students do not realize the contradicting information. These students do not assimilate the new information nor change their schemas. There is also a possibility that students do realize that they are confronted with contradicting information and experience confusion. According to Piaget (1977) these students can neglect the information and do nothing with the information, but are aware of the inconsistency. The other possibility is that students somewhat reshape their schemas or completely reshape their old schema and replace it for a new schema (Piaget, 1977).

Limón (2001) argued that conceptual change is likely to happen when the conflict is meaningful for students. She identified several factors that are important for students to create a meaningful conflict. These factors were classified in the following three categories: individual factors associated with learner, the factor associated with the teacher and the factors associated with the social environment (Limon, 2001).

For this research project the following two individual factors are important: prior knowledge and motivation. For achieving conceptual change it is important to know what the prior knowledge is, otherwise it remains unknown what students initial conceptions are and how these conceptions changed during the intervention (Limòn, 2001). Besides, a conflict can be more meaningful for a student when existing ideas are challenged (Limòn, 2001). According to Champagne, Klopfer and Gunstone (1982) misconceptions are a common element of students' prior knowledge. Most students have already developed their own conceptions about scientific phenomena and these conceptions are different from the ideas and theories educated in the classroom, therefore these conceptions are called misconceptions. These misconceptions are surprisingly consistent among students and are persistent to change by traditional education (Champagne, Klopfer & Gunstone, 1982). Therefore, common misconceptions can be used to determine students' prior knowledge and can be used to create a meaningful conflict for students. The second individual factor that is important for this research is motivation. The following factors are important for promoting conceptual change: self-efficacy, values, control beliefs and goals (Pintrich, Marx and Boyle, 1993)

The following factors associated with teacher are important for this study: the motivation of the teacher, the teachers teaching strategies and the level of training of the teacher (Limón, 2001). In this study, the teacher factors will be kept constant as much as possible. This means that the same teacher will do the teaching during the whole experiment. There is an uncertainty that the teacher does prefer one way of teaching. Especially, when the teacher is allowed to fill in the intervention in his/her own way. In addition, not allowing a teacher to design and regulate the lessons can have a negative influence on the teacher´s sense of ownership (Rutten, Van Joolingen & Van der Veen, 2016). This lack of ownership can influence the pedagogical interactions and affect the students' learning.

One important factor related to the social environment is whether students get the opportunity to discuss their ideas with their peers (Dreyfus, Jungwirth, & Eliovitch, 1990; Limón, 2001). Besides, several research projects indicated that a classroom discussion is important for students to develop their ideas (Mason, 1998; Mason & Santi, 1998). Furthermore, from a social constructivist point of view social interaction is important for knowledge construction (Lave & Wenger, 1991). According to Limòn (2001) the role of peers can have a positive influence on students' awareness of the conflict. She indicated that the relation between role of peers and conceptual change is not completely clear and further research needs to clarify this relation (Limòn, 2001). Therefore, in this study the cognitive conflict strategy will be combined with a teaching method where students are allowed to discuss with their peers.

In this research project the cognitive conflict strategy will be combined with the teaching method Peer Instruction, which is a teaching method where students get the opportunity to discuss their ideas with their peers (Mazur, 1997). Peer Instruction is developed based on the idea the that students can better explain a new concept to their peers than a teacher, because a student remembers the difficulties related to learning the new concept (Crouch, Watkins, Fagen, & Mazur, 2007). According to Crouch and colleagues (2007) the teaching method Peer Instruction starts with introducing the topic. Subsequently, the teacher introduces a conceptual question related to the topic. Thereafter, the teacher asks the students to think individually about the ConcepTest question. The students need to report their answer to the teacher, for example with a mobile device. The subsequent phase is the peer discussion phase where students need to convince their neighbours that their answer is correct. The peer discussion phase will only be executed when 35 to 70 % answered the ConcepTest correct, otherwise the ConcepTest could be too easy or too difficult. Thereafter, the teacher introduces for a second time the same ConcepTest and asks the students to answer the question for a second time. After the students voted, the teacher will provide the correct explanation for the

ConcepTest. Thereafter the cycle repeat itself with a new concept (Crouch, Watkins, Fagen, & Mazur, 2007).

For investigating the learning effects during a Peer Instruction lesson, a ConcepTest is commonly used (Crouch et al., 2007). New ConcepTest questions were designed for this research project. According to Crouch et al. (2007) there are no strict rules for designing a ConcepTest, but there are the following rules of thumb: students need to think and do not need a piece of paper to write things down, the incorrect answers are plausible, the ConcepTest is not too difficult or too easy, only one concept is involved in the ConcepTest and the ConcepTest is understandable. Unfortunately, a ConcepTest cannot be used twice, otherwise the students copy their answer from their teacher or neighbours (Smith, Wood, Adams, Wieman, Knight, Gulid, & Su, 2009; Smith, Wood, Krauter, & Knight, 2011). Smith et al. (2009) used isomorphic questions to determine the “real” learning gain during the peer discussion. An isomorphic question is a different question than the ConcepTest question but it measures the same concept (Smith et al., 2009). Therefore, the same rules of thumb for the ConcepTest will be used for designing the isomorphic questions. Additionally, the ConcepTests and isomorphic questions are reviewed by different physics teachers to make sure that they are measuring the same concept.

Consequently, the aim of this study is to determine the learning effects of combining a cognitive conflict strategy with the teaching method Peer Instruction. This will be investigated by comparing an experimental group with a control group. In the experimental group, students will get a Peer Instruction lesson with a cognitive conflict strategy and in the control group the students will get a Peer Instruction lesson without a cognitive conflict strategy. Based on this theoretical framework the researcher defined the following research questions related to a meaningful conflict and conceptual change:

-*What is the effect on students learning gain when an intentional cognitive conflict is created during Peer Instruction compared to regular Peer Instruction without a cognitive conflict strategy?*

-*Which factors are important for students to create a meaningful cognitive conflict that leads to conceptual change when an intentional cognitive conflict is created during Peer Instruction?*

Furthermore, the main focus in studies related to a cognitive conflict strategy is on how much students learned from a specific concept and there is less focus on other learning effects such as students’ view on the nature of science (e.g. Limon, 2001). Therefore, this study will also focus on whether a lesson with a cognitive conflict strategy has an influence on students´ views on the Nature of Science.

According to Lederman (1992) the Nature of Science refers to all the issues related to the development of scientific knowledge. In this research project the definition of Lederman, Abd-El-Khalick, Bell and Schwartz (2002) will be used. One important characteristic is that that scientific knowledge is tentative. This means that scientific ideas and theories are changing, because scientists continuously develop new ideas and theories. Furthermore, scientific knowledge is based on observations and inference. This means that science to a certain extent is based on observing the natural phenomena with our senses. Based on these observations scientists make statements which are not observable with our senses. Nevertheless, there is still a possibility that scientists make errors during the process of observing and inferring. Another characteristic is that scientific knowledge is theory-laden. This means that scientists are influenced by their preconceived ideas and background. This affects what scientists observe and how they carry out their investigation. Furthermore, scientists do not follow a step-by-step plan, therefore a universal scientific method does not exist. Another characteristic is that scientists need to use their creativity and imagination to develop a new theory. The last characteristic is that scientific knowledge is affected by the society (Lederman, Abd-El-Khalick, Bell and Schwartz, 2002).

Thomas Kuhn (1962) described how science developed over time. He tried to explain with his model the Nature of Science. According to Kuhn (1962) scientists are doing science in a paradigm. A paradigm consists of all the theories, ideas, instruments and values of the scientific community. Normally, scientists can explain the observations from their paradigm. This period is called normal science. After a while scientists will find anomalies or cannot explain several observations from their paradigm. This leads to a crisis where the common theory is no longer working in several situations. At a certain moment a scientist invents a new theory that provides a better explanation for the unexplained phenomena. This can lead to a scientific revolution where scientists accept the new theory and reject the old theory. According to Thomas Kuhn a paradigm shift happens where the scientists are rejecting the old paradigm and develop a new paradigm. After the paradigm shift the cycle will start again with a new period of normal science. To summarize, Kuhn (1962) described with his theory a fictitious cycle that begins with normal science, followed by a crisis, this will be followed by a scientific revolution that will eventually lead to a paradigm shift (Thwink, 2014). Therefore, a difference between the experimental and control group is expected, because the lesson from the experimental group resembles more the fictitious cycle described by Kuhn (1962). Based on this theoretical framework the researcher defined the following research question:

-*What are the effects on students views on the Nature of Science when an intentional cognitive conflict is created during peer instruction compared to regular peer instruction without a cognitive conflict strategy?*

2. Method

To answer the research questions, a quasi-experimental pre- posttest design was followed.

2.1 Participants

Three teachers and six classes from a secondary school in the Netherlands participated in this study. In total 158 students participated aged 15 and 16 years old (ninth grade). The lessons were executed at students' own school and with their own teacher and class. Classes were randomly assigned to either the experimental or the control group, on the condition that each teacher had one experimental and one control group.

2.2 Research design

The research design is schematically given in Figure 1. In the first column is the original peer instruction given. In the second column, the lesson structure for the experimental group is given and in the third column the lesson structure for the control group is given. The phases that differ from the original peer instruction are indicated with a colour and capital letter.

Three misconceptions were discussed in the experimental and control group according to the lesson structure shown in Figure 1. After the teacher completed the lesson structure for the first misconception, the lesson structure repeated itself with the second misconception (for more information see appendix A and B). The first misconception that was discussed is related to the idea, which was shared by Barlow and Becquerel, that electrical current is consumed by a resistor or light bulb (Licht, 1987). The second misconception is related to the idea from Aristoteles that a force is required to move an object with a constant velocity (Tao & Gunstone, 1999). The last misconception is related to the idea that an object launched from a canon will not follow a parabolic trajectory, rather a trajectory that is similar to trajectory from the impetus theory (McCloskey, 1983; Tao & Gunstone, 1999).

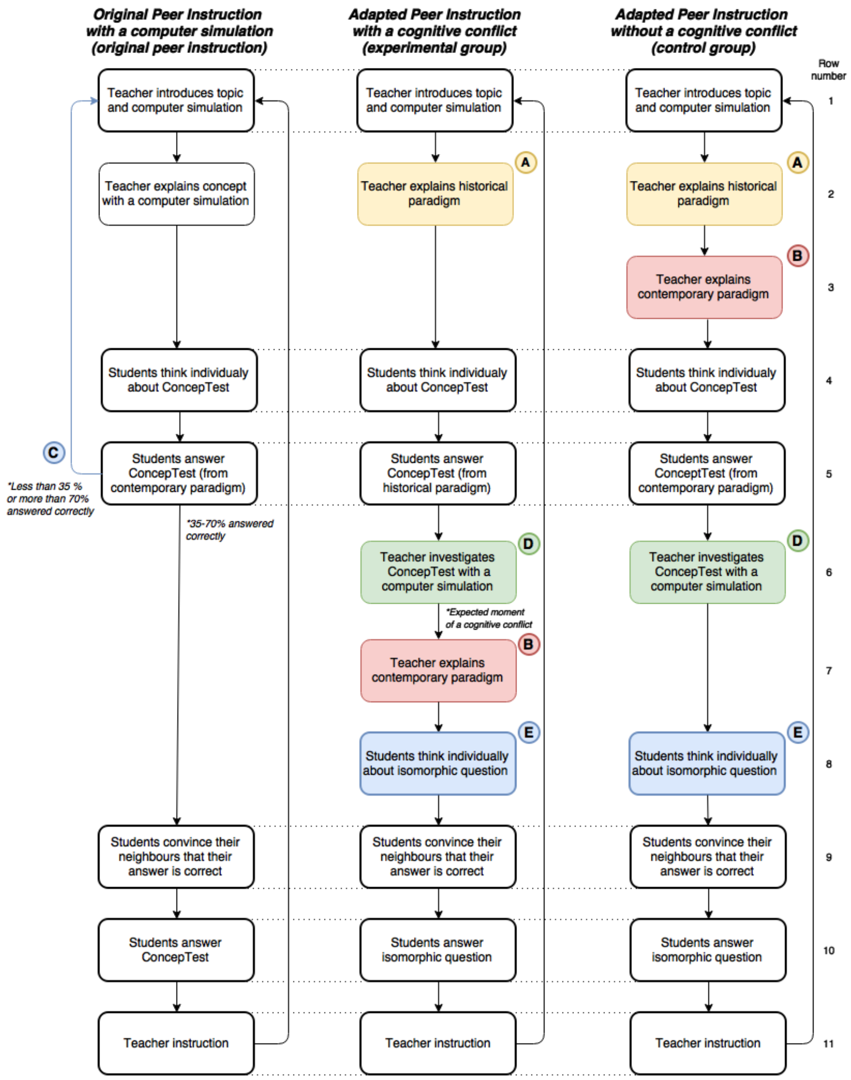


Figure 1: The lesson structure for the experimental- and control group compared to the original peer instruction.

In the experimental group, all the known conditions were met to create a meaningful cognitive conflict. The teachers started in the experimental group with introducing the misconception and computer simulation (row number 1). For this research project computer simulations were used from PhET and The Physics Aviary. The teachers briefly discussed and showed the main characteristics of the computer simulation. The teacher only showed which variables can be changed and not what will happen when these variables are changed. This "orientation" phase is similar to the original Peer Instruction.

Thereafter the teachers explained an outdated historical paradigm that we nowadays regard as incomplete or incorrect (row number 2). This historical paradigm is connected to the prior knowledge of the students, which is important to create a meaningful cognitive conflict (Limòn, 2001). This condition is satisfied because the historical theories and ideas are closely related to students pre- and misconceptions (Fischer, 1983). Explaining an outdated historical paradigm is not incorporated in the original Peer Instruction (phase indicated with a capital letter A).

After the teacher explained the historical paradigm the teacher introduced a ConcepTest question and asked the students to think individually what would be the correct answer from the historical paradigm (row number 4). The ConcepTest question is related to the computer simulation and the students needed to predict what will happen if one variable is changed. For example, for the misconception about electrical current the following ConcepTest was used in the experimental group: “You learnt about how Barlow and Becquerel thought about electrical current. Based on their ideas, which of the following statements should be correct about the left electrical circuit in Figure 2?”. In the control group the question was formulated slightly different: “You learnt about how Ohm thought about electrical current. Based on his ideas, which statement should be correct?”. The answers in the experimental and control group where identical. Option A was: “The current through the left current meter is bigger”. Option B was: “The current through the right current meter is bigger.” Option C was: “The current through both current meters is equal.”. And option D was. Based on the ideas from Barlow and Becquerel options A and B should be “correct”, neglecting the direction of the current. And based on the ideas from Ohm option C should be correct.

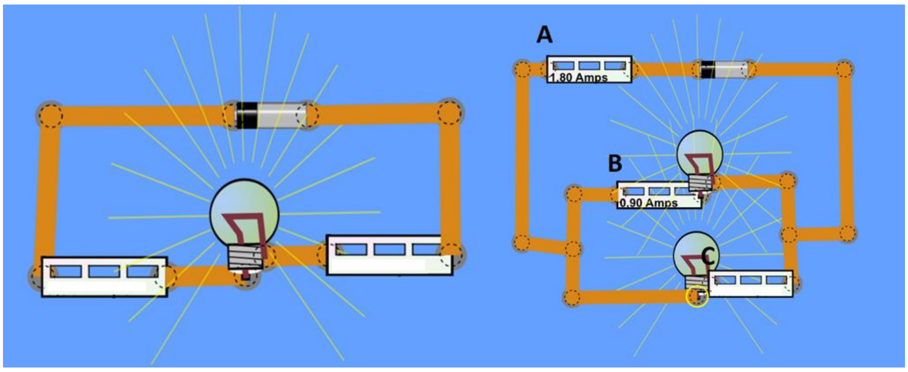


Figure 2: On the left the ConcepTest and on the right the isomorphic question created with Circuit Construction Kit (DC only) from PhET (n.d.).

After the students thought individually about the ConcepTest they needed to answer the question with their mobile device (row number 5). These two phases are almost identical to the original Peer Instruction (see rows number 4 and 5). The only difference is that the condition that more than 35 % and less than 70% of the students need to answer the ConcepTest correctly was removed in the experimental- and control group (indicated with the capital letter C), because the researcher expected that in the experimental group most students should answer the ConcepTest incorrect from the contemporary paradigm. Therefore, less than 35 % students could answer the ConcepTest correct.

Thereafter, the teacher used a computer simulation to investigate the ConcepTest question, this phase in not incorporated in the original Peer Instruction (row number 6). The researcher expected that the students will discover that the historical way of thinking is not in line with what will happen in the computer simulation. Expectantly some students will experience dissatisfaction with their prior ideas, which is one of the four conditions defined by Posner and colleagues (1982). Thereafter, the teacher introduces a “fruitful” new theory which can explain the previous ConcepTest question (row number 7). The researcher expects that students will adopt this fruitful new theory.

After the teacher explained the contemporary paradigm the teacher introduced the isomorphic question and asked the students to think individually about the isomorphic question (row number 8). In the experimental and control group the following isomorphic question was used: “You learnt about how Ohm thought about electrical current. Based on his ideas, which statement about the right electrical circuit in Figure 2 should be correct?”. The first option to answer was: “The current through current meter C is smaller than the current through A and B”. The second option was: “The current through the current meter C is equal to the current through current meter A.”. The third option was: “The current through current meter C is equal to the current through current meter B.”. And the last voting option was: “The current through current meter C is somewhere between current meters A and B.”. The correct answer from the perspective of Ohm is the third answer.

In the original Peer Instruction, the ConcepTest is asked for a second time, but in this research project the “second” ConcepTest is changed for an isomorphic question, because the students learnt during the investigation of the ConcepTest what the correct answer should be. Therefore, the students could answer the “second” ConcepTest correctly based on the learnt information, without using the “fruitful” new theory.

Subsequently, the students needed to convince their neighbours that their answer is correct (row number 9). This phase is similar to the original Peer Instruction. Subsequently, the teacher asked the students to answer the isomorphic question with their mobile device (row number 10). The cycle in the experimental group will end with a teacher instruction, where the teacher provides the correct explanation for the isomorphic question. The teacher is free to provide his or her own explanation and can organise a group discussion.

In the control group, not all the conditions were met to create a meaningful conflict.
The only difference between the control- and experimental group is the order of the activities during the lesson (see rows number 3 and 7) and that the students were asked to answer the ConcepTest from the contemporary paradigm (see row number 5). The rest of the lesson is entirely the same.

2.2.2 Instruments

The ConcepTests and isomorphic questions were answered with the online voting tool Socrative. The students could login via their mobile phones or laptop and sign in with a room number. The researcher monitored the results during the lessons and reported the number of students that voted directly to the teacher. The teacher continued with the lesson when all the students had answered the ConcepTest or isomorphic question.

2.2.3 Data analysis

The students who answered the ConcepTest or isomorphic question neither from the historical nor contemporary paradigm were excluded. Therefore, the number or percentage of students that voted incorrectly from the contemporary paradigm is equal to the number or percentage of student that voted correctly from the historical paradigm. For investigating the results for the ConcepTests and isomorphic questions between the experimental- and control group a chi-square test of homogeneity was used when the assumptions were met. In the case that the sample size was inappropriate a Fisher’s exact test was used. For analysing how the students voted for the ConcepTest and isomorphic question together, the students were split in four groups. The differences between the individual groups were investigated with multiple z-tests of two proportions. In the case that the sample size was inappropriate multiple Fisher’s exact tests was used. Furthermore, Bonferroni corrections were used to correct for multiple comparisons.

2.3 Meaningful conflict

2.3.1 Semi-structured interviews

Six students who participated in the experimental group were interviewed in peer discussion pairs by the researcher. All the interviews were audio recorded with permission of the students and the data was analysed with the software programme ELAN (2017).

2.4 Nature of Science

2.4.1 Instrument

Chen (2006a) developed a broad questionnaire that investigates students views on science and education, the so called VOSE questionnaire. The questionnaire begins with posing a question or statement. Related to this statement or question several responses are formulated, where students need to indicate whether they agree or disagree with the statement (See appendix C). Not all the items of the original VOSE questionnaire were used in this study, because the questionnaire is not appropriate for ninth graders (Chen, 2006a). Although, Aikenhead and Ryan (1992) argued that the VOSE questionnaire may be applicable for tenth- to twelfth-grade students. Consequently, the irrelevant items were not used in this study.

2.4.2 Data analysis

For analysing students views on the nature of science a Mann Whitney U test was used. All the assumptions for the Mann-Whitney U test were met, because the dependent variable is ordinal (agreement with the response), the independent variable is categorical (experimental- or control group) and the participants from both group only participated in their "own" group. The shape of the distributions for the experimental- and control group were assessed to determine whether the median or mean rank need to be used. Furthermore, to correct for multiple comparisons a Bonferroni correction was used.

3. Results

3.1 Cognitive conflict and learning gain

Not all the data was used for answering the first research question, because several students did not answer the ConcepTest and/or isomorphic question. Therefore, these students were excluded from the data. The results will be discussed per misconception.

In the experimental group the teacher only explained the historical paradigm before the ConcepTest question. Compared to the control group where the teacher explained as well as the historical as contemporary paradigm. Therefore, the expectation is that more students in the experimental group will answer the ConcepTest from the historical paradigm. In other words, more students in the experimental group will answer the ConcepTest incorrect. How students voted for the ConcepTest and isomorphic questions for the misconception about electrical current is shown in Figure 3. In the experimental group answered 69.2 % of the students the ConcepTest incorrect. Compared to the control group where 21.3 % answered the ConcepTest incorrect. The difference between the experimental and control group was investigated with a chi-square test of homogeneity and appeared to be statistically significant with a difference in proportion .479, $p < .005$. This means that the first step of the cognitive conflict strategy appeared to be effective.

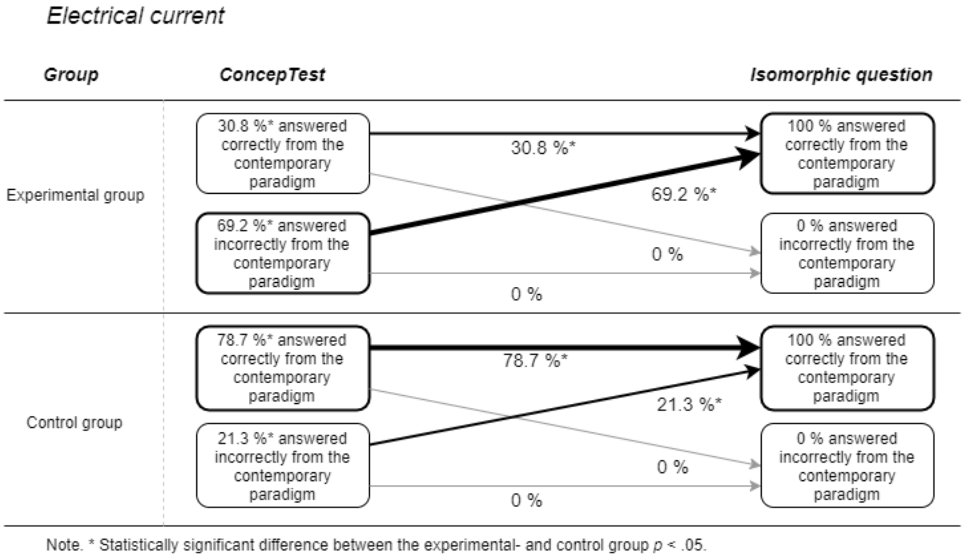


Figure 3: Results for the misconception about electrical current for the experimental and control group.

The assumption is that students in the experimental group who answered the ConcepTest incorrect will discover that their answer is incorrect when the teacher investigates the ConcepTest with a computer simulation. Subsequently, the teacher introduces only in the experimental group a fruitful theory that provides an explanation for the ConcepTest question. Therefore, is expected that more students in the experimental group will answer the ConcepTest incorrect and the isomorphic question correct. This appeared to be the case for the misconception about electrical current, because 69.2 % of the students followed this "path" in the experimental group, versus 21.3 % in the control group. With a chi-square test of homogeneity and Bonferroni correction this difference was statistically significant, $p < .0125$. Furthermore, was expected that more students in the control group who answered the ConcepTest incorrect will stick to their incorrect ideas and answer the isomorphic question also incorrect. This appeared not to be the case, because the difference between the experimental and control group was not statistically significant.

Consequently, was expected that more students in the experimental group answered the isomorphic question correct than in the control group. This was not the case, because in both groups all the students answered the isomorphic question correct. This means that the cognitive conflict strategy did not lead to more conceptual change in the experimental group than in the control group.

The results for the misconceptions about Aristoteles mechanics are given in Figure 4. Unfortunately, there were neither statistically significant differences between the experimental and control group for the ConcepTest question, nor the isomorphic question, nor the followed "path". This means that the cognitive conflict strategy was not effective for this misconception.

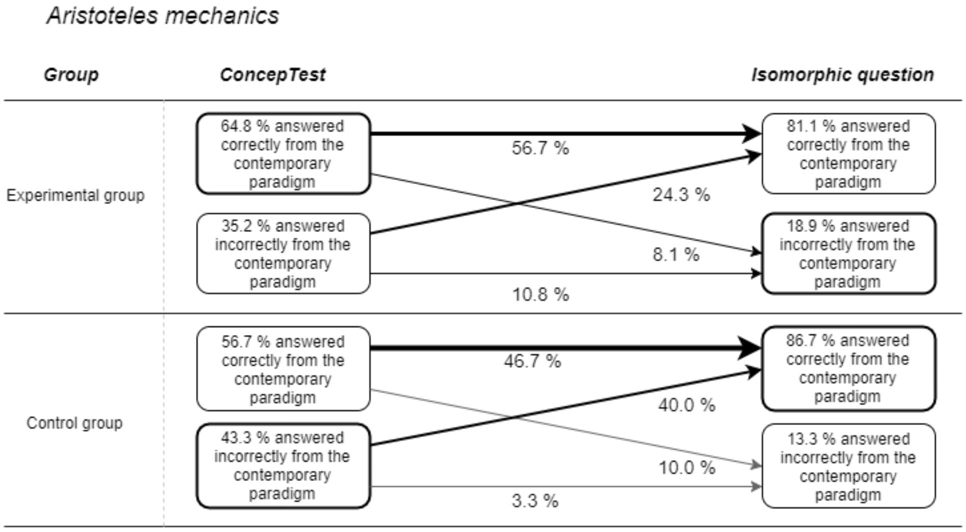


Figure 4: Results for the misconception about Aristoteles mechanics for the experimental and control group.

How students voted for the ConcepTest and isomorphic question for the misconception about the impetus theory is given in Figure 5. The cognitive conflict strategy appeared to be effective, because 94.4 % of the students answered the ConcepTest incorrect in the experimental group, versus 56.0 % in the control group. With a chi-square test of homogeneity was determined that the difference was statistically significant, in proportions of .384, $p < .001$. Nevertheless, the cognitive conflict strategy did not lead to a higher learning gain in the experimental group, because 11.1 % of the students in the experimental group answered the isomorphic question correct and in the control group 28.0 %. The difference was statistically significant with a difference in proportions of .169, $p = .029$. This can be explained because statistically significant more students in the experimental group answered as well as the ConcepTest as the isomorphic question incorrect (experimental group $N = 45$, 83.3 % versus control group $N = 16$, 32.0 %), $p < .0125$. Multiple Fisher's exact tests (2 x 2) with a Bonferroni correction were used for investigating these differences. Furthermore, statistically significantly more students in the control group answered the ConcepTest correct and the isomorphic question compared to the experimental group (control group $N = 20$, 40.0 % versus experimental group $N = 3$, 5.6 %), $p < .0125$.

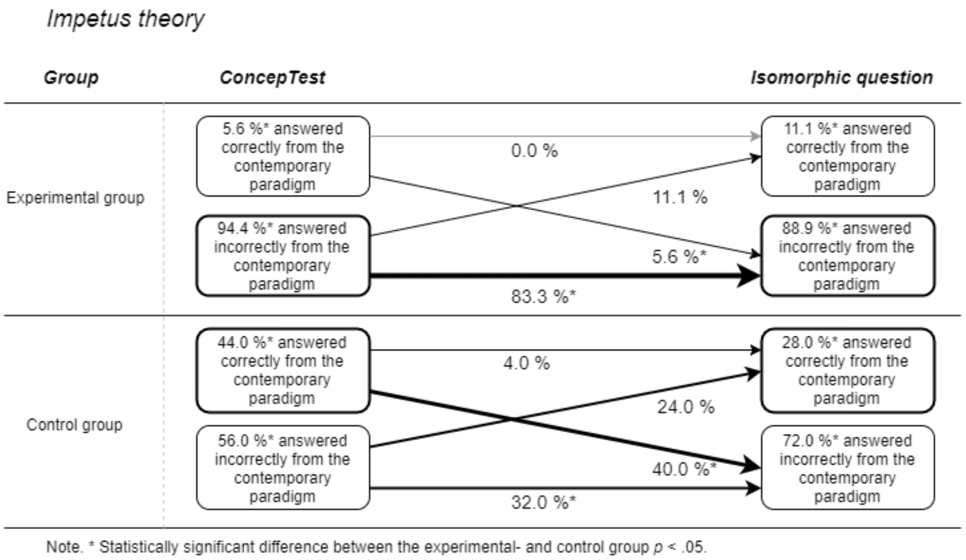


Figure 5: Results for the misconception about impetus theory for the experimental and control group.

3.2 Meaningful conflict

For investigating the third research question semi-structured interviews were used to investigate which factors are important for students to create a meaningful conflict. The students were interviewed together with their peer discussion partner.

On the one hand, for some students the cognitive conflict strategy appeared to be successful and leaded to conceptual change. For example, Student 1 and 2 answered the ConcepTest incorrect for the misconception about electrical current and discovered during the investigation of the ConcepTest that their answer was incorrect. Both student reacted surprised when they discovered that their answer was incorrect. Student 1 said that she thought the following when the teacher explained the ConcepTest: “When the teacher gave an explanation, I thought of course, maybe I could have come up with the same explanation.”. Both students indicated they used the contemporary paradigm to answer the isomorphic question and answered the question correctly.

Student 5 also answered the ConcepTest incorrect for the misconception about electrical current. Student 6 admitted that she initially did not know the correct answer and said the following: “First I had to think about it, I did not know immediately the correct answer.”. Student 5 also answered the ConcepTest incorrect, but denied during the interview that she answered the ConcepTest incorrect. Subsequently, the researcher asked what they thought when the teacher investigated the ConcepTest, student 5 responded: “I thought yes, I chose the right answer.”. Student 5 also answered the same question for student 5 and said: “Student 6 thought shit…”. Student 6 reacted confused and said: “I forgot what I thought.”. Nevertheless, both students accepted the contemporary theory and answered the isomorphic question correct. Student 5 said about the contemporary theory: “I thought this theory could also be possible.”.

Furthermore, student 3 and 4 did answer the ConcepTest incorrect for the misconception related to Aristoteles mechanics. Student 3 indicated that he did not completely understood the ConcepTest question, he said during the interview: “I did not know that the person in the computer simulation had pushed the box.”. During the investigation of the ConcepTest both students discovered that their answer was incorrect and contradicted their expectations. Both students thought that the speed of a moving box in a frictionless environment should decrease. Student 4 said: “I thought it was strange that the box did not stop moving, because the speed of the box need to decrease somehow.”. Student 3 said “I thought when the box bounced against the wall, the speed of the box should somehow decrease.”. Thereafter the teacher introduced the contemporary theory. Student 3 indicated that the contemporary paradigm was difficult and student 4 indicated that the contemporary paradigm confused her. Nevertheless, both students used the contemporary paradigm correctly to underpin the isomorphic question. But they did not answer the isomorphic question correctly, because they did not neglect the air resistance.

On the other hand, the cognitive conflict strategy did not always work. Some students already knew or accepted the correct explanation. For example, student 5 and 6 already knew the correct explanation for the misconception about Aristoteles mechanics and answered the ConcepTest correct. In addition, student 3 and 4 could remember the correct explanation from the previous year. Unfortunately, students 3 and 4 did not answer the ConcepTest correct, because they answered the question correct from the historical paradigm. Student 4 said: “I answered the question from the historical perspective, because that was the instruction.”.

Furthermore, some students did not experience dissatisfaction with their current ideas, because they did not observe that their answer was incorrect. For example, student 1 and 2 did not observe the correct trajectory for a packet that is dropped from a moving drone, for the misconception about the impetus theory. Student 2 said: "It was difficult to see, because the line of the trajectory was not visible.". Student 1 said she observed that: "the line was steep". Thereafter, the interviewer asked what they remembered from the contemporary paradigm. The students did not remember the "core message". Consequently, both students answered the isomorphic question incorrect. Student 1 said that: "I am still wondering why the parabolic trajectory should be the correct answer.".

In addition, student 3 and 4 answered the ConcepTest incorrect for the misconception about the impetus theory. Both students discovered during the investigation of the ConcepTest that their answer was incorrect and assumed that the line cannot be a steep line. Based on this assumption student 4 answered the isomorphic question incorrect. Therefore, the student used information from investigating the ConcepTest to answer the isomorphic question.

3.3 Nature of science

For all the individual items, a Mann-Whitney U test was performed to determine whether there were differences in agreement with a response to a statement or question between the experimental- and control group. A Bonferroni correction was used to correct for multiple comparisons (after correction $p < .00172$ was statistically significant). All the results for the VOSE questionnaire are given in appendix E. Unfortunately, there were no statistically significant results. Nevertheless, this part of the study is explorative, therefore we will focus on the interesting differences between the experimental and control group.

The first question was defined as follows: "When two different theories arise to explain the same phenomenon, will scientists accept the two theories at the same time?" (Chen, 2006b). We will focus on two responses, which are given in Table 1.

Table 1

The first question is defined as follows: "When two different theories arise to explain the same phenomenon, will scientists accept the two theories at the same time?" (Chen, 2006b). The responses related to this question and students' agreement with these responses are given in this table.

	Median				
	Exp. group	Con. group	Mann-Whitney *U* test	*Z*-score	*p* value
1b: "Yes, because the two theories may provide explanations from different perspectives, there is no right or wrong." (Chen, 2006b).	4	3	2483.0	-1.929	.054
1e: "No, the academic status of each theory will influence scientists' acceptance of the theory." (Chen, 2006b).	2	3	2458.5	-2.136	.033

Notes. 1= strongly disagree, 2 = disagree, 3 = neutral, 4 = agree and 5 =strongly agree

The first response was defined as follows: "Yes, because the two theories may provide explanations from different perspectives, there is no right or wrong." (Chen, 2006b). Students agreed with this statement in the experimental group (median: 4). In comparison to the control group where the students responded neutral (median: 3). Unfortunately, this difference was not statistically significant, *U* = 2483.0, *z* = -1.929, *p* = .054. According to Chen (2006a) this response is related to the nature of science issue “subjectivity and objectivity”. The other response was defined as follows: “No, the academic status of each theory will influence scientists’ acceptance of the theory.” (Chen, 2006b). Students agreement with this response for the experimental- (mean rank = 71.23) and control group (mean rank = 86.15) was close to statistically significantly, *U* = 2458.5, *z* = -2.136, *p* = .033. This response is related to the nature of science issue “validation of scientific knowledge” (Chen, 2006a).

The fourth statement was defined as follows: “Even if the scientific investigations are carried out correctly, the theory proposed can still be disproved in the future.” (Chen, 2006b). We will only discuss the responses given in Table 2.

Table 2

The fourth statement is defined as follows: “Even if the scientific investigations are carried out correctly, the theory proposed can still be disproved in the future.” (Chen, 2006b). The responses related to this statement and students”.The responses related to this question and students’ agreement with these responses are given in this table.

	Mean rank				
	Exp. group	Con. group	Mann-Whitney *U* test	*Z*-score	*p* value
4a: “Scientific research will face revolutionary change, and the old theory will be replaced.” (Chen, 2006b).	85.43	72.15	2557.5	-1.983	.047

There was a difference in students’ agreement related to the following response: “Scientific research will face revolutionary change, and the old theory will be replaced.” (Chen, 2006b). The difference between the experimental (mean rank = 85.43) and control group (mean rank = 72.15) was close to statistically significant, *U* = 2557.5, *z* = -1.983, *p* = .047. This response is related to the nature of science issue “tentativeness” (Chen, 2006a).

The sixth statement was defined as follows: “Most scientists follow the universal scientific method, step-by-step, to do their research.” (Chen, 2006b). Only the responses given in Table 3 will be discussed.

Table 3

The sixth statement is defined as follows: “Most scientists follow the universal scientific method, step-by-step, to do their research.” (Chen, 2006b). The responses related to this statement and students’ agreement with these responses are given in this table.

	Median/mean rank*				
	Exp. group	Con. group	Mann-Whitney *U* test	*Z*-score	*p* value
6a: “The scientific method ensures valid, clear, logical and accurate results. Thus, most scientists follow the universal method in research.” (Chen, 2006b).	4	3	2174.0	-2.463	.014
6f: “No matter how the results are obtained, scientists use the scientific method to verify it.” (Chen, 2006b).	82.90*	65.87*	2107.5	-2.504	.012

Notes. 1= strongly disagree, 2 = disagree, 3 = neutral, 4 = agree and 5 =strongly agree

The first response was formulated as follows: “The scientific method ensures valid, clear, logical and accurate results. Thus, most scientists follow the universal method in research.” (Chen, 2006b). Students in the experimental group appeared to agree with this response (median = 4) and the students in the control group responded neutral (median = 3). This difference was close to statistically significantly different, U =2174.0, z = -2.463, p = .014. The other response was defined as follows: “No matter how the results are obtained, scientists use the scientific method to verify it.” (Chen, 2006b). The difference between the experimental- (mean rank = 82.90) and the control group (mean rank = 65.87) was close to statistically significantly different, U =2107.5, z = -2.504, p = .012. According to Chen (2006a) both responses are related to the Nature of Science issue: “scientific methods”.

4. Discussion and conclusion

On the one hand, the first step of the cognitive conflict strategy appeared to be successful, because more students answered the ConcepTest incorrect in the experimental group than in the control group. For this was assumed that students who answered the ConcepTest incorrect thought according to the historical paradigm. On the other hand, the teacher asked the students explicitly in the experimental group to answer the ConcepTest from the historical paradigm. Therefore, some students answered the ConcepTest incorrect, although they knew that their answer was incorrect. During the interviews students 3 and 4 indicated that they could remember the correct explanation from last year, but answered the question incorrect because the teacher explicitly asked to answer the question from the historical perspective. Therefore, they answered the ConcepTest incorrect. This implicates that measuring the number of students is not representative for the number of students that thought according to the historical paradigm. This problem can be solved by not asking students explicitly to answer the ConcepTest question from the historical perspective. Therefore, we recommend asking students to answer the question based on what they think.

Furthermore, the first step of the cognitive conflict strategy appeared not to be effective for the misconception about Aristoteles mechanics. Student 3 said during the interview that he did not fully understood the ConcepTest question. He thought that is was not possible that the box had been pushed. In addition, during one of the lessons a student stated that: “The box is just standing still on the picture.”. The teacher said “Yes” and the student responded: “Okay, it is clear!” Subsequently, another student asked: “Whether it was possible that the box had been pushed?”. This indicates that some students thought that they had to say something about the static picture and did not understand that the picture was a snapshot from a computer simulation. Therefore, the ConcepTest question could be interpreted in different ways. This could have been the reason why there is not a difference between the experimental and control group (Crouch et al., 2007). Nevertheless, it is still possible that some students experienced dissatisfaction with their prior ideas and learnt from the ConcepTest question (Crouch et al., 2007). For example, student 3 and 4 discovered that their thinking was incorrect and used the contemporary paradigm to underpin correctly the isomorphic question. To avoid ambiguous question Crouch and colleagues (2007) recommended to pilot the ConcepTest questions. For this study the ConcepTests and isomorphic questions were only reviewed by three teachers, which appeared to be insufficient.

The first step of the cognitive conflict strategy appeared to work, but it did not lead to more conceptual change in the experimental group. Therefore, this study raised the following question: “Why did the cognitive conflict strategy not lead to a higher learning gain in the experimental group than in the control group?”.

Surprisingly, there was an opposite effect for the misconception about the impetus theory. More students in the control group answered the isomorphic question correct than in the experimental group. This can be explained by the fact that one of the teachers in the experimental group did not show properly what the correct answer was for the ConcepTest. Therefore, students did not observe that their answer was incorrect. This was the case for student 1 and 2 who did not observe the correct answer from the contemporary perspective. They observed that the projectile followed a “steep” trajectory, instead a parabolic trajectory. Therefore, these students did not experience dissatisfaction with their initial ideas, which is one of the four criteria for conceptual change (Posner et al., 1982). The same teacher adapted his teaching strategy based on his experiences with the experimental group. During the investigation of the ConcepTest in the control group the teacher explicitly mentioned that the parabolic trajectory was the correct answer. This could explain why statistically significantly more students in the control group answered the isomorphic question correct in the control group than in the experimental group. For further research, will be recommended to use a computer simulation which also shows the path of the projectile. So, that students can compare their predicted trajectory with the “real” trajectory.

For the misconception about electrical current all the students in the experimental and control group answered the isomorphic question correct. On the one hand, this can be explained by the fact that the topic is closely related to students’ prior knowledge, because electrical current was already discussed last year. Therefore, the interventions in the experimental- and control group could function to activate students’ prior knowledge. On the other hand, the isomorphic question could be too easy or not measuring the appropriate concept.

Furthermore, some students said that the contemporary paradigm was complicated. For example, Student 1 and 2 did not remember the contemporary paradigm for the impetus theory. What could have happened is that these students were unable to fit the contemporary idea into their existing schemas and rejected the old theory (Piaget, 1977). In addition, there were also students who made assumptions based on the ConcepTest questions and used these assumptions to answer the isomorphic question. For example, student 4 assumed that the line could not be a steep line, because the steep line was incorrect for the ConcepTest question. Therefore, some students answered the isomorphic question incorrect, because they used their intuition or the historical paradigm to answer the isomorphic question.

For the VOSE questionnaire there were no statistically significant differences between the experimental- and control group for students views on the Nature of Science. Nevertheless, there were a few differences between the experimental- and control group which were interesting for this study. However, the differences between the experimental and control group were small. These differences were related to the following Nature of Science issues: objectivity and subjectivity, validation of scientific knowledge, tentativeness and the scientific method.

For the issue “objectivity and subjectivity” it appeared that students in the experimental agreed with the idea that scientist will accept two ideas, when there are two possible explanations, compared to the control group where students responded more neutral. Objectively, researchers are not able to judge which theory is better (Chen, 2006a). Nevertheless, researchers are influenced by personal beliefs which influence whether they accept or reject a theory (Chen, 2006a). In the experimental group for the issue "validation of scientific knowledge" students thought that whether a scientific theory will be accepted does not depend on the status of the theory. According to Chen (2006a) the scientific community is biased and will be influenced by the status of the theory. For the issue related to "tentativeness of science" students in the experimental group agreed more with the idea that there will be a scientific revolution, compared to the control group. It appeared that the students in the experimental group did more agree with the ideas of Thomas Kuhn. Furthermore, students in the experimental group did more agree with the idea that there exists something like a universal scientific method, compared to the control group where students responded more neutral. According to the scientific community there does not exist something as a universal scientific method (Chen, 2006a).

The effects on students learning and views on the nature of science were small. This is in line with many research projects which implemented a cognitive conflict strategy (e.g. Champagne, Gunstone, & Klopfer, 1985; Limón & Carretero, 1997). Furthermore, Limon (2001) indicated that it is unlikely to expect that conceptual change will happen in a relatively short lesson. Each lesson took approximately 30 minutes and each misconception was discussed in approximately 10 minutes. This relatively short time may have influenced the effectiveness of the interventions. Therefore, we recommend to investigate whether a longer intervention has a bigger effect on students learning. Furthermore, the complexity of factors related to the teacher influenced how the lessons were performed. For example, the teachers did not always follow the lesson structure, because they were not able to remember the lesson structure. In addition, the teachers learnt from the first lesson and adapted their second lesson, which had an influence on the quality of the lessons. Therefore, piloting the experimental and control lesson could have helped to identify problems related to the lesson structure, ConcepTests and isomorphic questions.

5. Literature

Aikenhead, G. S., & Ryan, A. G. (1992). The development of a new instrument: "Views on Science-Technology-Society" (VOSTS). *Science Education*, *76*(5), 477-491.

Champagne, A., Gunstone, R. & Klopfer, L. (1985). Effecting changes in cognitive structures among physics students. In L. West & A. Pines, Eds., *Cognitive Structure and Conceptual Change* (163-187), Orlando: Academic Press.

Champagne, A., Klopfer, L., & Gunstone, R. (1982). Cognitive research and the design of science instruction. *Educational Psychologist*, *17*, 31-53.

Chen, S. (2006a). Development if an instrument to assess views on Nature of Science and attitudes toward teaching science. *Science Education, 90*(5), 803-819.

Chen, S. (2006b). Views on science and education (VOSE) questionnaire. *Asia-Pacific Forum on Science Learning and Teaching, 7*(2).

Crouch, C. H., Watkins, J., Fagen. A. P., & Mazur, E. (2007). Peer instruction: Engaging students one-on-one, all at once. In E. F. Redish, & P. Cooney, Eds., *American Association of Physics Teachers*, College Park: MD.

Dreyfus, A., Jungwirth, E., & Eliovitch, R. (1990). Applying the "cognitive conflict" strategy for conceptual change—some implications, difficulties and problems. *Science Education*, *74*, 555–569.

ELAN (Version 5.0.0-beta) [Computer software]. (2017, April 18). Nijmegen: Max Planck Institute for Psycholinguistics. Retrieved from https://tla.mpi.nl/tools/tla-tools/elan/

Fischer, K. W. (1983). Developmental levels as periods of discontinuity, *New Directions for Child and Adolescent Development, 1982*(21), 5-20.

Kuhn, T. S. (1962). *The Structure of Scientific Revolutions* (2nd ed.). Chicago, United States of America: The University of Chicago Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* Cambridge University Press, Cambridge.

Lederman, N. G. (1992). Students' and teachers' conceptions of the Nature of Science: A review of the research. *Journal of Research in Science Teaching, 29*(4), 331-359.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of Nature of Science questionnaire: Toward valid and meaningful assessment of learners' conceptions of Nature of Science. *Journal of Research in Science Teaching, 39*(6), 497-521.

Licht, P. (1987). Vakbegrippen als alternatief. *Verslag woudschotenconferentie natuurkunde* (pp. 1-10).

Limón, M. (2001). On the cognitive conflict as an instructional strategy for conceptual change: A critical appraisal. *Learning and Instruction, 11*(4-5), 357-380.

Limón, M., & Carretero, M. (1997). Conceptual change and anomalous data: A case study in the domain of natural sciences. *European Journal of Psychology of Education, 12*(2), 213–230.

Mason, L. (1998). Sharing cognition to construct scientific knowledge in school context: The role of oral and written discourse. *Instructional Science, 26*(5), 359–389.

Mason, L., & Santi, M. (1998). Discussing the greenhouse effect: Children's collaborative discourse reasoning and conceptual change. *Environmental Education Research, 4*(1), 67–85.

Mazur, E. (1997). *Peer Instruction: A User's Manual.* Prentice Hall, N.J.

McCloskey, M. (1983). Intuitive physics. *Scientific American, 248*(4), 114-122.

Pearsall, N. R., Skipper, J. E., & Mintzes, J. J. (1997). Knowledge restructuring in the life sciences: A longitudinal study of conceptual change in biology. *Science Education, 81*, 193–215.

PhET. (n.d.-a). Circuit Construction Kit (DC only) (3.20) [Computer Simulation]. Retrieved from https://phet.colorado.edu/en/simulation/legacy/circuit-construction-kit-dc

Piaget, J. (1977). *The development of thought: Equilibration of cognitive structures*. New York: Viking Press.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 63*(2), 167–200.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211–227.

Rutten, N., van Joolingen, W., R., & van der Veen, J. T. (2016). Investigating an intervention to support computer simulation use in whole class teaching. *Learning: research and practice, 2*(1), 27-43.

Smith, M. K., Wood W. B., Krauter, K., Knight, J. K. (2011). Combining peer discussion with instructor explanation increases student learning from in-class concept questions. *CBE-Life Sci Educ. 10*(1), 55-63.

Smith, M. K., Wood, W. B., Adams, W. K., Wieman, C., Knight, J. K., Gulid, N., & Su, T. T. (2009). Why peer discussion improves student performance on in-class concept questions. *Science, 323*(5910). 122-124.

Spada, H. (1994). Conceptual change or multiple representations? *Learning and Instruction, 4*, 113-116.

Tao, P. K., & Gunstone, R. F. (1999). The process of conceptual change in force and motion during computer-supported physics instruction. *Journal of Research in Science Teaching, 36*(7), 859-882.

Thwink. (2014). Normal Science. Retrieved from http://www.thwink.org/sustain/glossary/NormalScience.htm

Villani, A. (1992). Conceptual change in science and science education. *Science Education*, 76, 223–237.

6. Appendices

6.1 Appendix A

Docentenhandleiding

In deze docentenhandleiding wordt uitgelegd hoe het onderzoek uitgevoerd moet worden. Als eerste wordt het doel van het onderzoek besproken. Daarna wordt besproken hoe de structuur van de lessen eruit ziet en als laatste wordt besproken wat er verwacht wordt van de docent die de lessen uitvoert.

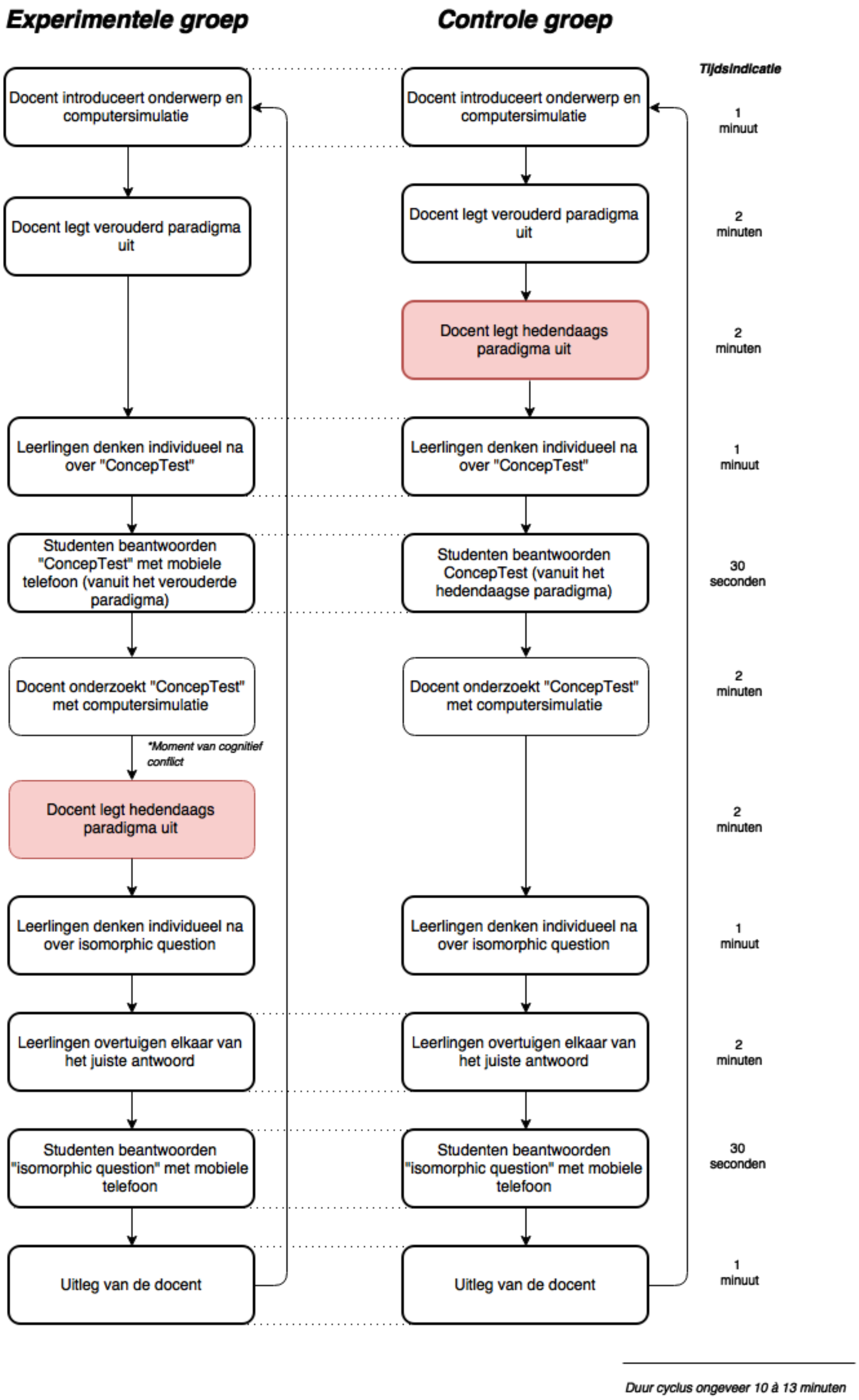
In dit onderzoek worden twee verschillende lessen gegeven door één docent. Iedere les wordt gegeven aan een andere klas van hetzelfde niveau en met hun eigen docent. De klassen worden opgesplitst in een experimentele- en controlegroep. In de experimentele groep wordt door de structuur van de les een cognitief conflict gecreëerd en in de controlegroep wordt geen cognitief conflict gecreëerd. Het doel van het onderzoek is om te onderzoeken in welke mate een cognitief conflict invloed heeft op de leeropbrengst van de leerlingen. Daarnaast wordt er onderzoek gedaan in welke mate de lesopbouw invloed heeft op hoe leerlingen tegen de aard van de wetenschap aankijken.

De algemene opbouw van de lessen is schematisch weergegeven in tabel 1. De lessen van de experimentele- en controlegroep beginnen met het opstarten en inloggen bij het stem programma Socrative. Daaropvolgend worden de verschillende misvattingen/onderwerpen besproken. De vierde misvatting/onderwerp wordt alleen besproken, in samenspraak met de onderzoeker, als er voldoende tijd over is. De les wordt afgesloten met een vragenlijst die de leerlingen moeten invullen. Na de les neemt de onderzoeker enkele leerlingen mee om te interviewen. Het interviewen van de leerlingen gebeurt individueel.

Tijdsindicatie (50 minuten)	*Wat gaan we doen?*
3 minuten	Opstarten van de les -Leerlingen loggen in met hun mobiele telefoons of laptops
10-13 minuten	Misvatting/onderwerp 1: Stroomverbruik
10-13 minuten	Misvatting/onderwerp 2: Lokaal en sequentieel redeneren
10-13 minuten	Misvatting/onderwerp 3: Mechanica van Aristoteles
Buffer	Misvatting/onderwerp 4: Impetus theorie
8-10 minuten	Leerlingen beantwoorden vragenlijst over de “Nature of Science”

Tabel 1: algemene structuur voor de lessen van de experimentele- en controlegroep

Het bespreken van de misvattingen/onderwerpen gebeurt volgens een vaste cyclus. Deze cyclus is in de experimentele groep anders dan in de controlegroep. De lescyclus voor het bespreken van de misvattingen in zowel de controle- als experimentele groep is schematisch weergegeven in figuur 1. In figuur 1 worden de misvattingen/onderwerpen benoemd als onderwerp, omdat leerlingen niet weten dat het om misvattingen gaat.



Figuur 1: de lescyclus voor het bespreken van de misvattingen

In zowel de experimentele- als de controlegroep begint de docent met het introduceren van het onderwerp en de bijbehorende computersimulatie. De docent laat zien hoe de computersimulatie eruitziet en welke variabelen veranderd kunnen worden. Echter, de docent laat nog niet zien wat er gebeurt als deze variabelen worden veranderd. Ter illustratie, bij de misvatting/onderwerp "stroomverbruik" laat de docent zien hoe een schakeling kan worden gebouwd en welke onderdelen er zijn. De docent bouwt nog niet de schakeling na die gebruikt wordt voor de ConcepTest "stroomverbruik" (zie: figuur 2).

Daaropvolgend legt de docent in zowel de controle- als de experimentele groep het verouderde paradigma/perspectief uit. Dit paradigma/perspectief is een oude theorie die tegenwoordig gezien wordt als “fout”. Het verouderde paradigma/perspectief wordt uitgelegd in de docentenhandleiding en dient gevolgd te worden door de docent.

Daarna legt de docent alleen in de controlegroep het hedendaagse perspectief uit. Dit is de “correcte” theorie die heden ten dage wordt gebruikt om het probleem te verklaren. Deze uitleg vindt alleen plaats in de controlegroep direct na het verouderde perspectief en wordt in de experimentele groep pas later uitgelegd. De uitleg voor het hedendaagse perspectief is ook terug te vinden in de docentenhandleiding.

Na de uitleg van het hedendaags paradigma/perspectief in de controlegroep moeten leerlingen individueel nadenken over een korte vraag. Het nadenken over deze vraag gebeurt dus in de experimentele groep direct na de uitleg van het verouderde paradigma/perspectief. Deze vraag wordt een “ConcepTest” genoemd, waarbij leerlingen moeten voorspellen wat er gebeurt als de docent een variabele verandert in de computersimulatie. De leerlingen krijgen één minuut de tijd om over deze vraag na te denken. Aansluitend beantwoorden de leerlingen de “ConcepTest” met hun mobiele telefoon of laptop. Na het beantwoorden gaat de docent de “ConcepTest” onderzoeken met behulp van de computersimulatie. Ter illustratie, bij de misvatting “stroomverbruik’ bouwt de docent de schakeling na en laat zien dat de stroomsterkte voor het lampje gelijk is aan de stroomsterkte achter het lampje. In de experimentele groep zullen de leerlingen erachter komen dat hun verwachtingen niet uitkomen, aangezien deze leerlingen redeneren vanuit het verouderde paradigma/perspectief, waardoor een cognitief conflict ontstaat.

Hierna komt de fase waarbij de docent alleen het hedendaagse paradigma/perspectief uitlegt in de experimentele groep. Aangezien deze uitleg al eerder is geweest in de controlegroep wordt deze niet voor een tweede keer uitgelegd. Na deze uitleg introduceert de docent een tweede vraag die niet hetzelfde is als de ConcepTest, maar wel hetzelfde concept toetst als de ConcepTest. Deze vraag wordt ook wel een “isomorphic question” genoemd. De leerlingen krijgen voor deze vraag één minuut individuele bedenktijd. Het is van belang dat de leerlingen in stilte over de vraag nadenken.

Daaropvolgend krijgen de leerlingen twee minuten de tijd om hun buurman te overtuigen dat hun antwoord juist is. Nadat de leerlingen geprobeerd hebben om elkaar te overtuigen, moeten de leerlingen hun stem uitbrengen met hun mobiele telefoon of laptop. Hierna geeft de docent een korte uitleg wat het correcte antwoord is en waarom dit het correcte antwoord is. Hierbij is de docent vrij om zijn eigen verhaal te vertellen. De docent is vrij om voor de uitleg nog een keer de computersimulatie te gebruiken. Hierna begint de cyclus opnieuw met een nieuwe misvatting/onderwerp.

Van de docent wordt verwacht dat hij of zij het verouderde paradigma en het hedendaags paradigma kan uitleggen. De docent moet zich in grote lijnen houden aan de inhoud van de misvattingen/onderwerpen, die op de volgende pagina’s worden besproken. Daarnaast moet de docent begrijpen hoe de computersimulaties werken en wat docent moet doen om de “ConcepTest” te onderzoeken. Al deze informatie is terug te vinden in de docentenhandleiding bij het desbetreffende onderwerp/misvatting. Bij beide lessen hoort een PowerPointpresentatie waarin de structuur van de les is verwerkt, en een tijdsindicatie wordt gegeven met behulp van een rode klok in de rechterbovenhoek. Deze PowerPointpresentaties zijn samen geleverd met de docentenhandleiding. De docent mag de inhoud van de PowerPointpresentatie aanpassen zolang dit gebeurt in samenspraak met de onderzoeker. De onderzoeker zal de lessen bijwonen en zorgen voor video-opnames van de lessen.

6.2 Appendix B

PowerPoint presentation for the experimental group.

Welkom

Ga naar:

- Link: https://b.socrative.com/login/student/
- Room Name: zie bord
- Kies je antwoord en druk op "submit answer"

Elektrische stroom

- Onderwerp: stroomverbruik

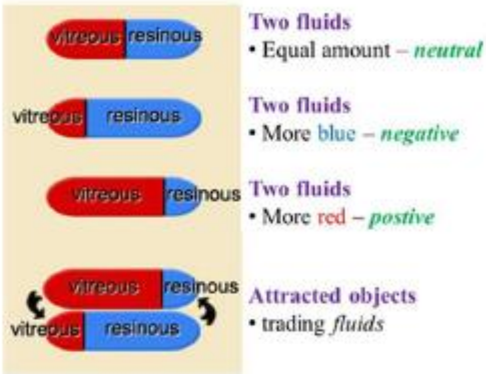
Simulatie Circuit Construction Kit (DC only) van PhET (z.j.-a).

Elektrische stroom (Twee vloeistof theorie)

De oude Grieken waren zich bewust van statische elektriciteit en dachten dat het uit twee substanties moest bestaan (Sabah, 2007). Charles du Fay (1698-1739) ontwikkelde de theorie waarbij elektriciteit bestaat uit twee vloeistoffen (Whittaker, 1910). Hij definieerde de volgende vloeistoffen (Whittaker 1910):

-Glasachtige vloeistof (Vitreous)

-Harsachtige vloeistof (Resinous)



Afbeelding van "The Nature of Electricity" (z.j.)

Elektrische stroom (Eén vloeistof theorie)

In de 18e eeuw kwam Benjamin Franklin (1706-1790) met een nieuwe theorie waarbij elektriciteit bestaat uit maar één vloeistof (Whittaker, 1910). Volgens deze theorie heeft een neutraal object een "normale" hoeveelheid elektrische vloeistof (Whittaker, 1910). Een positief geladen object heeft een overschot aan elektrische vloeistof en een negatief geladen object heeft een tekort aan elektrische vloeistof (Whittaker, 1910).

Elektrische stroom

Peter Barlow (1776-1862) en Antoine-César Becquerel (1788-1878) probeerden beide theorieën te onderzoeken (Licht, 1987). Een belangrijke aanname bij hun onderzoek was dat de stroom af zal nemen als deze door de schakeling stroomt (Licht, 1987).

In het geval van de één vloeistof theorie van Benjamin Franklin zou de elektrische vloeistof af moeten nemen tijdens het stromen door de draad (Licht, 1987). Dit betekende dat de sterkte van het magneetveld zou moeten afnemen om de draad. In het geval van de twee vloeistoffen theorie van Charles du Fay zouden de vloeistoffen in tegengestelde richting stromen (Licht, 1987). Beide vloeistoffen zouden tijdens het stromen afnemen maar doordat dit in tegengestelde richting gebeurt blijft de stroom constant (Licht, 1987). Dit zou betekenen dat het magneetveld om de draad gelijk moet blijven (Licht,1987).

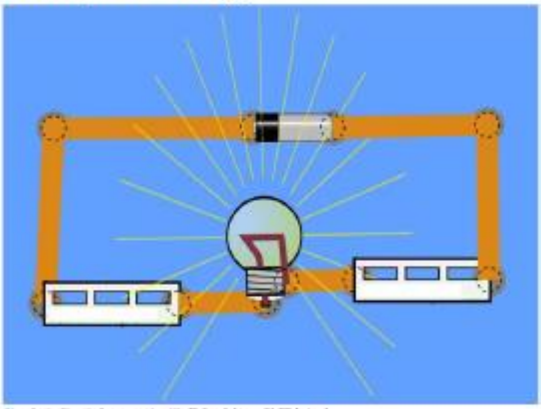
Samengevat: Barlow en Becquerel gingen er vanuit dat de elektrische stroom door een elektrische schakeling zou afnemen.

Individueel nadenken

1) Je hebt nu geleerd over hoe Barlow en Becquerel dachten over het verschijnsel elektrische stroom. Als je uitgaat van hun ideeën, welke stelling over het onderstaande figuur is dan juist?

a) De stroom door de linker ampèremeter is groter
b) De stroom door de rechter ampèremeter is groter
c) De stroom door beide ampèremeters is even groot
d) Geen van de bovenstaande stellingen is juist

Stemmen via socrative



Simulatie Circuit Construction Kit (DC only) van PhET (z.j.-a).

Onderzoeken ConcepTest

- https://phet.colorado.edu/en/simulation/legacy/circuit-construction-kit-dc

Hedendaags perspectief

Peter Barlow (1776-1862) en Antoine-César Becquerel (1788-1878) konden niet aantonen dat het magnetisch veld om de draad afnam (Licht, 1987). Men concludeerde dat de elektrische stroom uit twee elektrische vloeistoffen moest bestaan (Licht, 1987). Becquerel toonde later in zijn carrière aan dat de totale stroom door de gehele schakeling gelijk is (Shedd & Hershey, 1913).

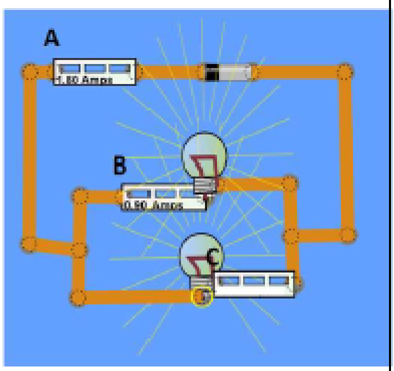
Becquerel toonde later in zijn carrière aan dat de totale stroom door de gehele schakeling gelijk is (Shedd & Hershey, 1913). Deze kennis is van essentieel belang geweest voor het onderzoek van Georg Ohm en de ontwikkeling van de wet van Ohm (Shedd & Hershey, 1913). De wet van Ohm gaat ervan uit dat de stroomsterkte door een schakeling recht evenredig is met de spanning. Dit wil zeggen dat als de stroomsterkte twee keer zo groot wordt, dan wordt de spanning ook twee keer zo groot. Oftewel, de hoeveelheid stroom die door een weerstand stroomt, is afhankelijk van de grootte van de weerstand en de sterkte van de spanning over de weerstand. Hierdoor is er volgens Ohm geen sprake van stroomverbruik in een weerstand, maar van energieverbruik.

Samengevat: Volgens Ohm is er geen sprake van stroomverbruik, maar van energieverbruik. De stroom door een weerstand is recht evenredig met de spanning over de weerstand

Individueel nadenken

2) Je hebt nu geleerd over hoe Ohm dacht over het verschijnsel elektrische stroom. Als je uitgaat van zijn ideeën, welke stelling is dan juist over de stroom door ampèremeter C in het onderstaande figuur?

a) De stroom door ampèremeter C is kleiner dan de stroom door ampèremeters A en B
b) De stroom door ampèremeter C is gelijk aan de stroom door ampèremeter A
c) De stroom door ampèremeter C is gelijk aan de stroom door ampèremeter B
d) De stroom door ampèremeter C ligt tussen de waarden van de ampèremeters A en B

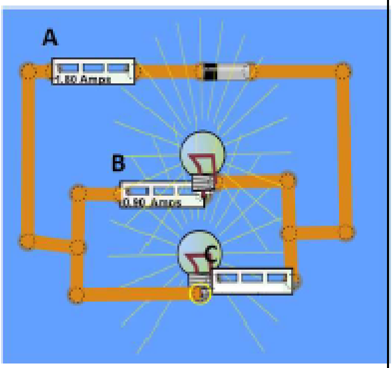


Simulatie Circuit Construction Kit (DC only) van PhET (z.j.-a).

Overtuig je buurman of buurvrouw van je antwoord

2) Je hebt nu geleerd over hoe Ohm dacht over het verschijnsel elektrische stroom. Als je uitgaat van zijn ideeën, welke stelling is dan juist over de stroom door ampèremeter C in het onderstaande figuur?

a) De stroom door ampèremeter C is kleiner dan de stroom door ampèremeters A en B
b) De stroom door ampèremeter C is gelijk aan de stroom door ampèremeter A
c) De stroom door ampèremeter C is gelijk aan de stroom door ampèremeter B
d) De stroom door ampèremeter C ligt tussen de waarden van de ampèremeters A en B



Simulatie Circuit Construction Kit (DC only) van PhET (z.j.-a).

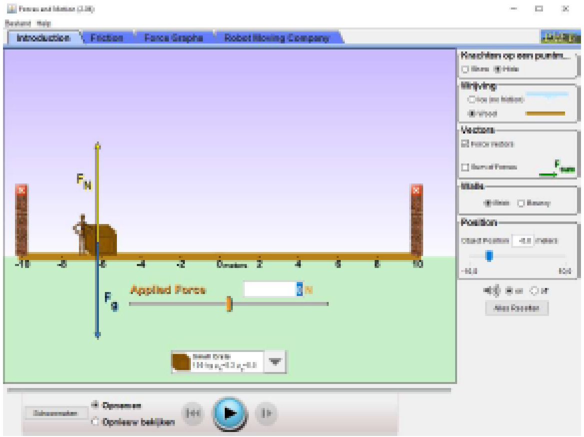
Stem via Socrative

Uitleg docent

- Vragen?
- https://phet.colorado.edu/en/simulation/legacy/circuit-construction-kit-dc

Mechanica van Aristoteles

- Onderwerp:
- krachten en beweging



Simulatie Forces and Motion van PhET (z.j.-b).

Mechanica van Aristoteles

Aristoteles (384 v.Chr - 322 v.Chr) ontwikkelde een theorie op het gebied van krachten en beweging (Aristotle, 1957). Hij observeerde dat een object in beweging gehouden moet worden door een kracht (Aristotle, 1957). Bijvoorbeeld, bij een paard met wagen zorgt het paard voor een kracht die de wagen in beweging houdt. Zodra het paard stopt met bewegen komt het paard met wagen tot stilstand. Aristoteles concludeerde dat een object waarop geen kracht meer werkt vanzelf tot stilstand komt (Aristotele, 1957).

Mechanica van Aristoteles

Daarnaast observeerde Aristoteles dat een pijl weggeschoten van een boog zijn snelheid voor langere tijd bewaart (Philoponus, 2014). Volgens Aristoteles behoudt de pijl zijn snelheid doordat de lucht een kracht uitoefent op de pijl (Philoponus, 2014). De lucht voor de pijl wordt weggedrukt en draait om de pijl heen om vervolgens weer aan te sluiten aan de achterkant van de pijl (Philoponus, 2014). Het aansluiten van de lucht aan de achterkant van de pijl levert een kracht die ervoor zorgt dat de pijl in beweging blijft (Philoponus, 2014) .

Samengevat: volgens Aristoteles ondervindt een bewegend object een kracht, zodra deze kracht afwezig is komt het object tot stilstand

Individueel nadenken

3) Vanuit het perspectief van Aristoteles, welke van de volgende uitspraken is juist over de beweging van de kist in het onderstaande figuur? (let op: er is geen weerstand!)

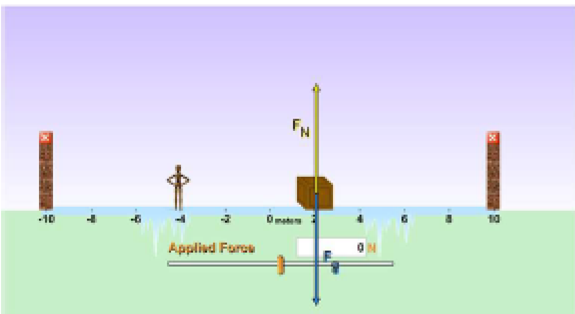
a) De kist staat stil en beweegt niet

b) De kist staat stil of de snelheid van de kist neemt af

c) De kist staat stil of beweegt met constante snelheid

d) Geen van de bovenstaande uitspraken is juist

Stemmen via Socrative



Simulatie Forces and Motion van PhET (z.j.-b).

Onderzoeken ConcepTest

- https://phet.colorado.edu/nl/simulation/legacy/forces-and-motion

Hedendaags perspectief

Isaac Newton (1643-1727) postuleerde in zijn eerste wet het volgende: als de nettokracht op een object nul is, staat het object stil of beweegt het zich in een rechte lijn door de ruimte. In zijn tweede wet postuleerde Newton het volgende: een object zal versnellen, vertragen of van richting veranderen als er een nettokracht op een object wordt uitgeoefend. In tegenstelling tot Aristoteles werkt er volgens Newton geen nettokracht op een object die zich met een constante snelheid voortbeweegt. Volgens Newton zorgt een nettokracht voor een verandering van de snelheid.

Samengevat: volgens Newton zal een object waar geen netto kracht op werkt stilstaan of met een constante snelheid bewegen. Een nettokracht zorgt voor een verandering van de snelheid.

Individueel nadenken

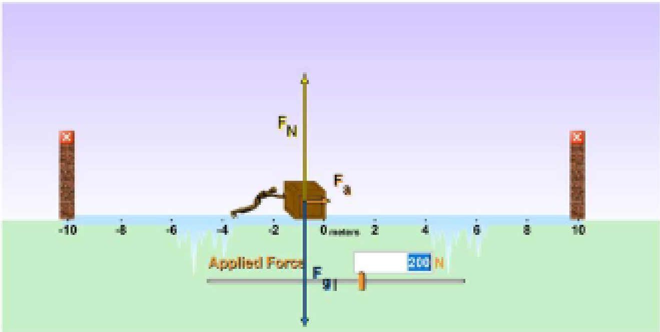
4) Vanuit het perspectief van Newton, wat gebeurt er met de snelheid van de kist zodra het persoon in het onderstaande figuur stopt met duwen? (Let op: er is geen weerstand!)

a) De snelheid van de kist blijft toenemen

b) De snelheid van de kist neemt af

c) De snelheid van de kist blijft constant

d) Dit is niet te bepalen



Simulatie Forces and Motion van PhET (z.j.-b).

Overtuig je buurman of buurvrouw van je antwoord

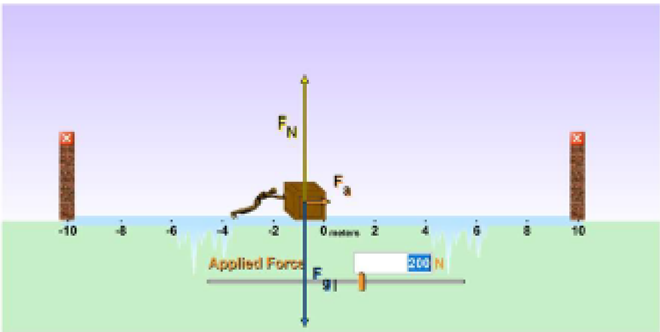
6) Vanuit het perspectief van Newton, wat gebeurt er met de snelheid van de kist zodra het persoon in het onderstaande figuur stopt met duwen? (Let op: er is geen weerstand!)

a) De snelheid van de kist blijft toenemen

b) De snelheid van de kist neemt af

c) De snelheid van de kist blijft constant

d) Dit is niet te bepalen



Simulatie Forces and Motion van PhET (z.j.-b).

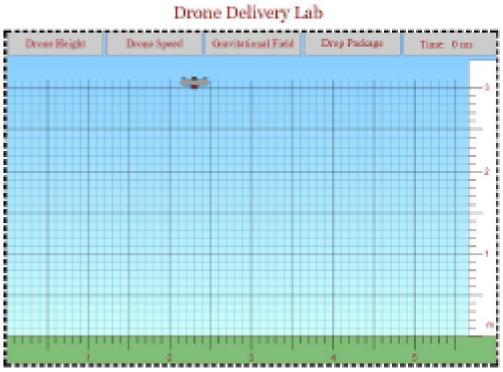
Stem via Socrative

Uitleg docent

- Vragen?
- https://phet.colorado.edu/nl/simulation/legacy/forces-and-motion

Traject van een projectiel

- Onderwerp: de impetus theorie



Simulatie Drone Delivery Lab van The Physics Aviary (z.j.-a).

De impetus theorie

John Philoponus (490-570) bouwde voort op de ideeën van Aristoteles (Zimmermann, 2013). Philoponus ging ervan uit dat als een object werd weggegooid, er een soort kracht aan het object werd gegeven (Zimmermann, 2013). Deze kracht nam af naarmate het object zich verder verplaatste (Zimmermann, 2013). Deze theorie werd verder ontwikkeld door Jean Buridan tot de "impetustheorie" (Klima, 2007). Volgens deze theorie had een bewegend object een bepaalde hoeveelheid "impetus" dat ervoor zorgde dat het object blijft voortbewegen in de richting van de snelheid (Klima, 2007). Naarmate het object verder bewoog nam, de hoeveelheid "impetus" af en op een bepaald moment nam de zwaartekracht het van de impetus over (Klima, 2007). Volgens deze theorie zal een object dat wordt weggegooid zich eerst voortbewegen in de richting van de snelheid en op een bepaald moment naar beneden gaan, doordat de zwaartekracht het wint van de impetus (Klima, 2007).

Samengevat: Volgens Buridan zal een projectiel zijn snelheid en richting behouden totdat op een bepaald moment de zwaartekracht het overneemt van de impetus.

Individueel nadenken

- 5) In de simulatie vliegt een drone met constante snelheid naar rechts (zie rode pijl). Op een bepaald moment laat de drone het projectiel los. Op het moment dat het projectiel op de grond landt, bevindt de drone zich op de rode stip. Vanuit het perspectief van Buridan, welk traject zal het projectiel in het onderstaande figuur volgen als het los wordt gelaten op de positie aangegeven in de afbeelding (verwaarloos de luchtweerstand)?

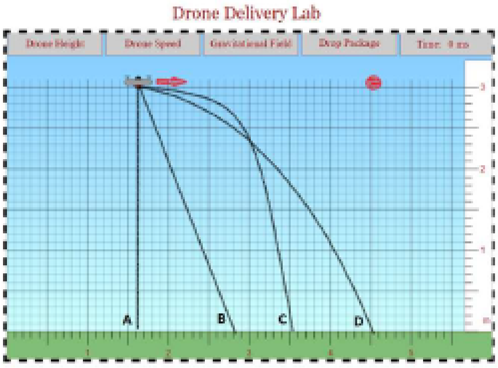
a) Traject A

b) Traject B

c) Traject C

d) Traject D

Stemmen via Socrative



Simulatie Drone Delivery Lab van The Physics Aviary (z.j.-a).

Onderzoeken ConcepTest

- http://www.thephysicsaviary.com/Physics/Programs/Labs/DroneDeliveryLab/index.html

Hedendaags perspectief

In 1609 publiceerde Galileo Galilei (1564-1642) zijn theorie over de beweging van projectielen (Naylor, 1975). In dit manuscript beschreef Galileo dat projectielen een gebogen pad zullen volgen die overeenkomt met een parabool.

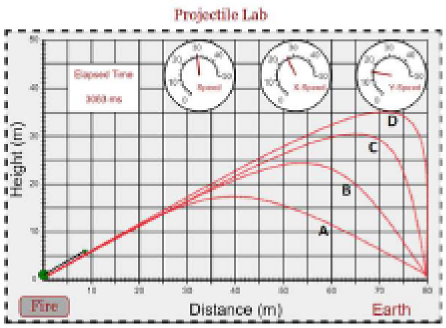
Vanuit het perspectief van Newton kan de beweging worden opgesplitst in een horizontale- en verticale component. In de horizontale component zal het projectiel zijn snelheid behouden en zich met een constante snelheid voortbewegen. In de verticale richting speelt de zwaartekracht een belangrijke rol. Die ervoor zorgt dat het object in de verticale richting in snelheid toeneemt. Het combineren van de horizontale- en verticale beweging resulteert in een parabolisch traject.

Samengevat: Volgens Galileo volgt een projectiel die wordt weggeschoten een parabolisch traject.

Individueel nadenken

- 6) Vanuit het perspectief van Galileo, welk traject zal het projectiel volgen in het onderstaande figuur als het wordt weggeschoten vanaf de oorsprong onder een hoek van 30 graden met een snelheid van 30 m/s(verwaarloos de luchtweerstand)?

a) Traject A
b) Traject B
c) Traject C
d) Traject D

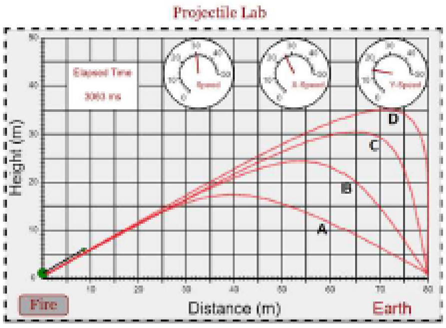


Simulatie Projectile Lab van Physics Aviary (z.j.-b).

Overtuig je buurman of buurvrouw van je antwoord

- 8) Vanuit het perspectief van Galileo, welk traject zal het projectiel volgen in het onderstaande figuur als het wordt weggeschoten vanaf de oorsprong onder een hoek van 30 graden met een snelheid van 30 m/s (verwaarloos de luchtweerstand)?

a) Traject A
b) Traject B
c) Traject C
d) Traject D



Simulatie Projectile Lab van Physics Aviary (z.j.-b).

Stem via Socrative

Uitleg docent

- Vragen?
- http://www.thephysicsaviary.com/Physics/Programs/Labs/ProjectileLab/index.html

Einde presentatie

- Vragenlijst invullen

Referenties

- Aristotle. Physics, Volume I: Books 1-4. Translated by P. H. Wicksteed, F. M. Cornford. Loeb Classical Library 228. Cambridge, MA: Harvard University Press, 1957.
- Whittaker, E., T. (1910). A History of the Theories of Aether and Electricity
- PhET. (z.j.-a). Circuit Construction Kit (DC only) (3.20) [Computer Simulatie]. Geraadpleegd van https://phet.colorado.edu/en/simulation/legacy/circuit-construction-kit-dc
- PhET. (z.j.-b). Forces and Motion (2.06) [Computer Simulatie]. Geraadpleegd van https://phet.colorado.edu/nl/simulation/legacy/forces-and-motion
- The Physics Aviary. (z.j.-a). Drone Delivery Lab [Computer Simulatie]. Geraadpleegd van http://www.thephysicsaviary.com/Physics/Programs/Labs/DroneDeliveryLab/index.html
- The Physics Aviary. (z.j.-b). Projectile Lab [Computer Simulatie]. Geraadpleegd van http://www.thephysicsaviary.com/Physics/Programs/Labs/ProjectileLab/index.html
- Sabah, N., H. (2007). *Electric Circuits and Signals*. Boca Raton, FL: CRC Press.
- The Nature of Electricity. (z.j.). Geraadpleegd van http://slideplayer.com/slide/3914409/
- Licht, P. (1987). Vakbegrippen als alternatief.
- Shedd, J. C., & Hersey, M. D. (1912). The History of Ohm's Law. *Populair Science Monthly, 83*, 599-614.
- Philoponus (2014). Philoponus: On Aristotele Physics 4.6-9. London, Verenigd Koningkrijk: Bloomsburry Academic.
- Naylor, R. H. (1975). An aspect of Galileo's study of the parabolic trajectory. *Isis 66*, 394-396.
- Zimmermann, F. (2013). Philoponus' impetus theory in the arabic tradition. *Bulletin of the institute of classical studies, 56*(s103), 161-169.
- Klima, G. (2007). Medieval Philosophy: Essential Readings with Commentary (1[e] ed.). Hoboken, Verenigde Staten: Wiley-Blackwell.

6.3 Appendix C

Vragenlijst m.b.t. de aard van de wetenschap (VOSE)

De vragen beginnen met een vraag of een statement. Daarop zijn verschillende antwoorden geformuleerd. Geef aan in welke mate je het eens bent met het gegeven antwoord (helemaal mee oneens, oneens, neutraal, mee eens of helemaal mee eens). Zet een cirkel om het bijbehorende cijfer in de kolom. In deze vragenlijst zijn geen goede of foute antwoorden. Bedankt voor het invullen!

1) Kunnen wetenschappers twee verschillende theorieën accepteren die één fenomeen verklaren, als beide theorieën in staat zijn om hetzelfde fenomeen uit te kunnen leggen?

	Helemaal mee oneens	Oneens	Neutraal	Mee eens	Helemaal mee eens
A) Ja, want wetenschappers kunnen niet objectief bepalen welke theorie beter is, daarom accepteren wetenschappers voorlopig beide theorieën.	1	2	3	4	5
B) Ja, want de twee theorieën kunnen een verklaring geven vanuit verschillende perspectieven, er is geen goede of foute theorie.	1	2	3	4	5
C) Nee, want wetenschappers kiezen een theorie waar ze het meest vertrouwd mee zijn.	1	2	3	4	5
D) Nee, wetenschappers kiezen de simpelste theorie en vermijden de complexe theorie.	1	2	3	4	5
E) Nee, de academische status van de wetenschapper die de theorie heeft verzonnen heeft invloed op welke theorie een wetenschapper kiest.	1	2	3	4	5
F) Nee, wetenschappers kiezen de theorie die het minste afwijkt van hun huidige opvattingen.	1	2	3	4	5
G) Nee, want er is maar één waarheid binnen de wetenschap, wetenschappers kiezen niet zomaar een theorie voordat ze bepaald hebben welke het beste is.	1	2	3	4	5

2) Wetenschappelijk onderzoek wordt beïnvloed door sociaal culturele factoren.

	Helemaal mee oneens	Oneens	Neutraal	Mee eens	Helemaal mee eens
A) Ja, sociaal culturele factoren beïnvloeden de richting en onderwerpen van wetenschappelijk onderzoek.	1	2	3	4	5
B) Ja, omdat wetenschappers die onderzoek doen worden beïnvloed door sociaal culturele factoren.	1	2	3	4	5
C) Nee, omdat wetenschappers goed zijn opgeleid en zich niet laten beïnvloeden door subjectieve factoren.	1	2	3	4	5
D) Nee, omdat wetenschap objectiviteit vereist, in tegenstelling tot de subjectiviteit van sociaal culturele factoren.	1	2	3	4	5

3) Gebruiken wetenschappers als ze onderzoek doen hun creativiteit?					
	Helemaal mee oneens	Oneens	Neutraal	Mee eens	Helemaal mee eens
A) Ja, creativiteit is een belangrijke bron van innovatie.	1	2	3	4	5
B) Ja, onderzoekers gebruiken in meer tot mindere mate hun creativiteit.	1	2	3	4	5
C) Nee, creativiteit kan niet samengaan met de logische wetenschappelijke principes.	1	2	3	4	5
D) Nee, creativiteit is niet betrouwbaar.	1	2	3	4	5

4) Zelfs wanneer wetenschappelijk onderzoek correct wordt uitgevoerd, kan de wetenschappelijke theorie in de toekomst ontkracht worden.					
	Helemaal mee oneens	Oneens	Neutraal	Mee eens	Helemaal mee eens
A) Wetenschappelijk onderzoek zal een revolutionaire verandering ondergaan, en de verouderde theorie wordt vervangen door een nieuwe theorie.	1	2	3	4	5
B) Wetenschappelijke veranderingen kunnen niet in een korte tijd worden bewerkstelligd, daarom wordt er vastgehouden aan de oorspronkelijke theorie.	1	2	3	4	5
C) Met de ontwikkeling van nieuwe data en informatie, zal de oorspronkelijke theorie completer en accurater worden, de oorspronkelijke wetenschappelijke theorie zal niet ontkracht worden.	1	2	3	4	5

5) Wat wetenschappers observeren wordt beïnvloed door de persoonlijke overtuigingen van de wetenschapper, daarom is het mogelijk dat wetenschappers niet hetzelfde observeren in precies hetzelfde experiment.					
	Helemaal mee oneens	Oneens	Neutraal	Mee eens	Helemaal mee eens
A) Observaties van wetenschappers verschillen, omdat verschillende overtuigingen kunnen leiden tot verschillende verwachtingen die invloed hebben op wat wetenschappers observeren.	1	2	3	4	5

B) Wat wetenschappers observeren is hetzelfde, omdat wetenschappers opgeleid in hetzelfde vakgebied soortgelijke ideeën hebben.	1	2	3	4	5
C) Wat wetenschappers observeren is hetzelfde, omdat wetenschappers zijn opgeleid in het loslaten van hun persoonlijke ideeën en zijn opgeleid in het objectief observeren.	1	2	3	4	5
D) Wat wetenschappers observeren is hetzelfde, omdat je bij observeren exact ziet wat er gebeurt en niks meer of minder. Feiten zijn feiten. Interpretaties kunnen verschillen per persoon, maar observaties zijn hetzelfde.	1	2	3	4	5
E) Wat wetenschappers observeren is hetzelfde, alhoewel subjectiviteit niet volledig kan worden vermeden bij het observeren. Wetenschappers gebruiken verschillende methoden om hun resultaten te verifiëren en hun objectiviteit te verbeteren.	1	2	3	4	5

6) Meeste wetenschappers volgen de universele wetenschappelijke methode, stap voor stap, om hun onderzoek uit te voeren (formuleren van hypotheses, onderzoek ontwerpen, data verzamelen en het trekken van conclusies).					
	Helemaal mee oneens	Oneens	Neutraal	Mee eens	Helemaal mee eens
A) De wetenschappelijke methode garandeert valide, duidelijke, logische en accurate resultaten. Daarom volgen de meeste wetenschappers de wetenschappelijke methode.	1	2	3	4	5
B) Meeste wetenschappers gebruiken de wetenschappelijke methode omdat het een logische procedure is.	1	2	3	4	5
C) De wetenschappelijke methode is bruikbaar in de meeste gevallen, maar garandeert geen resultaat. Daarom ontwikkelen wetenschappers ook nieuwe methoden.	1	2	3	4	5
D) Er bestaat helemaal niet zoiets als de wetenschappelijke methode., Wetenschappers gebruiken verschillende methoden om aan resultaten te komen.	1	2	3	4	5
E) Er is geen specifiek wetenschappelijke methode. Wetenschappelijke kennis kan per toeval worden ontdekt.	1	2	3	4	5
F) Het maakt niet uit hoe de resultaten zijn verkregen. Wetenschappers gebruiken de wetenschappelijke methode om hun resultaten te verifiëren.	1	2	3	4	5

Originele vragenlijst van Chen (2006b).

6.4 Appendix D

Table 1

Students thinking process during the misconceptions about electrical current.

Student	Acceptation historical paradigm	Answer for the ConcepTest	Investigation of the ConcepTest (Cognitive conflict)	Acceptation contemporary paradigm	Answer for the isomorphic question
Student 1 (Discussion pair 1)	Theory about historical paradigm is complicated. Did not fully understood the historical paradigm.	Doubtful the student says that she answered “correctly” from the historical paradigm.	Student observed that her answer was incorrect from the contemporary paradigm.	Student provides correct answer from the contemporary perspective.	Student answered the isomorphic question correctly from the contemporary perspective.
Student 2 (Discussion pair 1)	Theory about historical paradigm is complicated. Based her decision for the ConcepTest on the historical paradigm.	Answered question “correctly” from historical paradigm.	Student observed that her answer was incorrect from the contemporary paradigm.	Student provides correct answer from the contemporary perspective and uses information from investigating the ConcepTest to underpin her answer.	Student answered the isomorphic question correctly from the contemporary perspective.
Student 3 (Discussion pair 2)	Student rejects the historical paradigm and provides a correct explanation from the contemporary perspective.	Answered the ConcepTest from the historical paradigm.	Student observed that his answer was correct from the contemporary paradigm.	Student provides correct explanation from the contemporary perspective for the first isomorphic question	Student answered the isomorphic question correctly from the contemporary perspective.
Student 4 (Discussion pair 2)	Student rejects the historical paradigm and provides a correct explanation from the contemporary perspective.	Answered the ConcepTest from the historical paradigm, because that was the instruction.	Student observed that his answer was correct from the contemporary paradigm.	Student agrees with the explanation from student 3.	Student answered the isomorphic question correctly from the contemporary perspective.
Student 5 (Discussion Pair 3)	Students is able to recall the historical paradigm and said that she first thought that the historical paradigm could be possible.	Answered the ConcepTest from the historical paradigm. *	Student said that she was not surprised by the result and thought that students 6 was surprised.	Contemporary paradigm was too much text, therefore she had to read much quicker.	Student answered the isomorphic question correctly from the contemporary perspective.
Student 6 (Discussion Pair 3)	Student is able to recall the historical paradigm.	Answered the ConcepTest from the historical paradigm. *	Student denies that she was surprised and said that she forgot what she thought.	Contemporary paradigm was too much text, therefore she was not able to read everything.	Student answered the isomorphic question correctly from the contemporary perspective.

Notes. *Based on the results from Socrative.

Table 2

Students individual thinking process during the misconceptions about Aristoteles mechanics.

Student	Acceptation historical paradigm	Answer for the ConcepTest	Cognitive conflict	Acceptation contemporary paradigm	Answer for the isomorphic question
Student 3 (Discussion pair 2)	Difficult to understand the historical paradigm.	Student did not understand the ConcepTest. Student voted neither from the historical nor from the contemporary paradigm.	Student observed the correct answer from the contemporary paradigm and indicates that the observation contradicts his ideas.	Contemporary paradigm was difficult. Student used the contemporary paradigm correctly to underpin the isomorphic question.	Student answered the question from the historical paradigm because they did not neglect the air resistance.
Student 4 (Discussion pair 2)	Difficult to understand the historical paradigm.	Student did not understand the ConcepTest. Student voted neither from the historical nor from the contemporary paradigm.	Student observed the correct answer from the contemporary paradigm and indicates that the observation contradicts her ideas.	Contemporary paradigm confused the student. Student used the contemporary paradigm correctly to underpin the isomorphic question.	Student answered the question from the historical paradigm because they did not neglect the air resistance.
Student 5 (Discussion pair 3)	Student rejected historical paradigm and uses the contemporary paradigm.	Student did answer the question correctly from the contemporary paradigm.	Student did not experience a cognitive conflict, because the observation agreed with the expectation.	Student underpins the isomorphic question from the contemporary paradigm.	Student answered isomorphic question from the contemporary perspective.
Student 6 (Discussion pair 3)	Student rejected historical paradigm and uses the contemporary paradigm.	Student did answer the question correctly from the contemporary paradigm.	Student did not experience a cognitive conflict, because the observation agreed with the expectation.	Student underpins the isomorphic question from the contemporary paradigm.	Student answered isomorphic question from the contemporary perspective.

Table 3

Students individual thinking process during the misconceptions about the impetus theory.

Student	Acceptation historical paradigm	Answer to the ConcepTest	Cognitive conflict	Acceptation contemporary paradigm	Answer to the isomorphic question
Student 1	Decision for ConcepTest based on logical thinking	Student answered third ConcepTest "correctly" from the historical paradigm.	Students did not observe correctly. Student think that answer B for the third isomorphic question is correct from the contemporary paradigm.	Student answered the isomorphic question from the historical paradigm and indicates that she still do not know why the parabolic trajectory is the correct answer from the contemporary perspective.	Answered correctly from the historical paradigm.
Student 2	Decision for ConcepTest based on logical thinking	Student answered third ConcepTest "correctly" from the historical paradigm.	Students did not observe correctly. Student think that answer B for the third isomorphic question is correct from the contemporary paradigm.	Student provides for the isomorphic question an explanation from the historical paradigm.	Answered correctly from the historical paradigm.
Student 3	Student indicates that the historical paradigm did not fully connect with his prior ideas.	Student answered the third ConcepTest “correctly” from the historical paradigm.	Student observed the correct answer from the contemporary paradigm.	Student used information from the ConcepTest to answer the isomorphic question.	Answered correctly from the historical paradigm.*
Student 4	Student indicates that she answered the ConcepTest from the historical paradigm. She rejected the impetus image in the PowerPoint slides.	Student answered the third ConcepTest “correctly” from the historical paradigm.	Student observed the correct answer from the contemporary paradigm.	Student used information from the ConcepTest to answer the isomorphic question.	Answered correctly from the historical paradigm.*

Notes. * Based on the results from Socrative.

6.5 Appendix E

Table 4

The first question is defined as follows: "When two different theories arise to explain the same phenomenon, will scientists accept the two theories at the same time?" (Chen, 2006b). The responses related to this question and students' agreement with these responses are given in this table.

		Median		Mean rank					
	Responses	Experimental group	Control group	Experimental group	Control group	Similar distribution	Mann-Whitney U test	Z-score	*p* value
1a	"Yes, because scientists still cannot objectively tell which one is better, therefore, they will accept both tentatively." (Chen, 2006b).	3	3	79.96	77.97	No	3000.0	-.285	.775
1b	"Yes, because the two theories may provide explanations from different perspectives, there is no right or wrong." (Chen, 2006b).	4	3	84.57	71.17	Yes	2483.0	-1.929	.054
1c	"No, because the scientists tend to accept the theory they are more familiar with." (Chen, 2006b).	2	2	82.56	75.21	Yes	2790.0	-1.059	.289
1d	"No, because scientists tend to accept the simpler theories and avoid complex theories." (Chen, 2006b).	1	1	78.68	78.32	Yes	3026.0	-.062	.951
1e	"No, the academic status of each theory will influence scientists' acceptance of the theory." (Chen, 2006b).	2	3	71.23	86.15	No	2458.5	-2.136	.033
1f	"No, scientists tend to accept new theories which deviate less from the contemporary core scientific theory." (Chen, 2006b).	3	3	77.22	79.89	No	2933.5	-.386	.699
1g	"No, because there is only one truth, scientists will not accept any theory before distinguishing which is best." (Chen, 2006b).	3	3	81.84	75.97	Yes	2848.0	-.832	.406

Notes. 1= strongly disagree, 2 = disagree, 3 = neutral, 4 = agree and 5 =strongly agree

Table 5

The second statement is defined as follows: "Scientific investigations are influenced by socio-cultural values." (Chen, 2006b). The responses related to this statement and students' agreement with these responses are given in this table.

		Median		Mean rank					
	Responses	Experimental group	Control group	Experimental group	Control group	Similar distribution	Mann-Whitney U test	Z-score	*p* value
2a	"Yes, socio-cultural values influence the direction and topics of scientific investigations." (Chen, 2006b).	4	4	83.91	73.77	Yes	2680.5	-1.487	.137
2b	"Yes, because scientists participating in scientific investigations are influenced by socio-cultural values." (Chen, 2006b).	4	3	84.84	72.78	Yes	2605.0	-1.776	.076
2c	"No, scientists with good training will remain value-free when carrying out research." (Chen, 2006b).	3	3	80.48	77.43	No	2958.5	-.444	.657
2d	"No, because science requires objectivity, which is contrary to the subjective socio-cultural values." (Chen, 2006b).	3	3	81.70	75.13	No	2784.0	-.981	.327

Notes. 1= strongly disagree, 2 = disagree, 3 = neutral, 4 = agree and 5 =strongly agree

Table 6

The third question is defined as follows: "When scientists are conducting scientific research, will they use their imagination?" (Chen, 2006b). The responses related to this question and students' agreement with these responses are given in this table.

		Median		Mean rank					
	Responses	Experimental group	Control group	Experimental group	Control group	Similar distribution	Mann-Whitney U test	Z-score	*p* value
3a	"Yes, imagination is the main source of innovation." (Chen, 2006b).	4	4	84.60	72.08	No	2552.0	-1.840	.066
3b	"Yes, scientists use their imagination more or less in scientific research." (Chen, 2006b).	4	4	81.29	76.56	Yes	2892.5	-.734	.463
3c	"No, imagination is not consistent with the logical principles of science." (Chen, 2006b).	2	2	74.91	83.36	Yes	2747.0	-1.241	.215
3d	"No, imagination lacks reliability." (Chen, 2006b).	2	2	77.04	81.09	Yes	2919.0	-.580	.562

Notes. 1= strongly disagree, 2 = disagree, 3 = neutral, 4 = agree and 5 =strongly agree.

Table 7

The fourth statement is defined as follows: "Even if the scientific investigations are carried out correctly, the theory proposed can still be disproved in the future." (Chen, 2006b). The responses related to this statement and students' agreement with these responses are given in this table.

		Median		Mean rank					
	Responses	Experimental group	Control group	Experimental group	Control group	Similar distribution	Mann-Whitney U test	Z-score	*p* value
4a	"Scientific research will face revolutionary change, and the old theory will be replaced." (Chen, 2006b)..	4	4	85.43	72.15	No	2557.5	-1.983	.047
4b	"Scientific advances cannot be made in a short time. It is through a cumulative process; therefore, the old theory is preserved." (Chen, 2006b).	2	2	77.87	80.20	Yes	2986.5	-.338	.735
4c	"With the accumulation of research data and information, the theory will evolve more accurately and completely, not being disproved." (Chen, 2006b).	4	3	82.57	74.22	No	2714.5	-1.205	.228

Notes. 1= strongly disagree, 2 = disagree, 3 = neutral, 4 = agree and 5 =strongly agree

Table 8

The fifth statement is defined as follows: "Scientists' observations are influenced by personal beliefs; therefore, they may not make the same observations for the same experiment." (Chen, 2006b). The responses related to this statement and students' agreement with these responses are given in this table.

		Median		Mean rank					
	Responses	Experimental group	Control group	Experimental group	Control group	Similar distribution	Mann-Whitney U test	Z-score	*p* value
5a	"Observations will be different, because different beliefs lead to different expectations influencing the observation." (Chen, 2006b).	4	4	81.99	71.53	Yes	2521.0	-1.658	.097
5b	"Observations will be the same, because the scientists are trained in the same field hold similar ideas." (Chen, 2006b).	2	2	72.84	80.47	Yes	2594.0	-1.167	.243
5c	"Observations will be the same, because through scientific training scientists can abandon personal values to conduct objective observations." (Chen, 2006b).	3	3	73.56	76.53	No	2661.5	-.438	.661
5d	"Observations will be the same, because observations are exactly what we see and nothing more. Facts are facts. Interpretations may be different from one person to another, but observations should be the same." (Chen, 2006b).	3	3	76.44	73.46	Yes	2661.0	-.440	.660
5e	"Observations will be the same. Although subjectivity cannot be completely avoided in observation, scientists use different methods to verify the results and improve objectivity." (Chen, 2006b).	4	4	79.47	74.36	Yes	2728.0	-.755	.450

Notes. 1= strongly disagree, 2 = disagree, 3 = neutral, 4 = agree and 5 =strongly agree

Table 9

The sixth statement is defined as follows: "Most scientists follow the universal scientific method, step-by-step, to do their research." (Chen, 2006b). The responses related to this statement and students' agreement with these responses are given in this table.

		Median		Mean rank					
	Responses	Experimental group	Control group	Experimental group	Control group	Similar distribution	Mann-Whitney U test	Z-score	*p* value
6a	"The scientific method ensures valid, clear, logical and accurate results. Thus, most scientists follow the universal method in research." (Chen, 2006b).	4	3	82.89	66.78	No	2174.0	-2.463	.014
6b	"Most scientists use the scientific method because it is a logical procedure." (Chen, 2006b).	4	4	73.35	77.77	Yes	2645.0	-.702	.483
6c	"The scientific method is useful in most instances, but it does not ensure results; therefore, scientists invent new methods." (Chen, 2006b).	4	4	73.03	77.10	Yes	2620.6	-.618	.537
6d	"There is no so-called the scientific method. Scientists use any methods to obtains results." (Chen, 2006b).	3	3	75.07	73.91	Yes	2694.5	-.176	.861
6e	"There is no fixed scientific method; scientific knowledge could be accidently discovered." (Chen, 2006b).	3	3	77.84	70.98	No	2482.5	-1.016	.310
6f	"No matter how the results are obtained, scientists use the scientific method to verify it." (Chen, 2006b).	3	3	82.90	65.87	No	2107.5	-2.504	.012

Notes. Numbers for the medians mean: 1= strongly disagree, 2 = disagree, 3 = neutral, 4 = agree and 5 =strongly agree.