Learning Effects of Explicitly Teaching 'Cause-Effect Thinking' in Lower Secondary Science Education.

Author: Manon ten Asbroek
Studentnumber: 3613429
Research project: 30 ECTS
Supervisor: Dirk-Jan Boerwinkel
Second examinar: Wilmad Kuiper

Abstract: This study will focus on the evaluation of the learning effects of the educational material based on the guidelines from the Kennisbasis. The Kennisbasis is a curriculum framework for lower secondary education in the Netherlands that describes the science- and technology subjects in terms of three dimensions: core ideas, crosscutting practices and crosscutting concepts education in the Netherlands. The core ideas describe the knowledge students should have, crosscutting practices describe the skills scientists and engineers need in their daily work and crosscutting concepts are ways of reasoning that have proved helpful in generating research questions and approaches and providing a deeper insight in science. The study asks what the learning effects are of explicitly teaching the crosscutting concept cause-effect thinking in lower secondary science education. This question will be answered by qualitatively analysing three lessons in the subjects biology and physics in which cause-effect thinking is explicitly taught. During the lesson students make a scheme in which the main cause and effect and all the variables that will connect the main cause and effect to each other; a Cause-Effect Schemes (CES) The analysis of the lessons will consist of student survey questions, teacher interviews, lesson observations, analysing student assessment and categorising CES into the categories of Hennessey. Results of this analysis show that when students are taught about cause-effect thinking via CES, students become more competent in making a CES and in the skill cause-effect thinking. Another learning effect is that approximately half of all students and the teachers involved find that cause-effect thinking helps students in their learning. Students and teacher both see differences in cause-effect thinking between the subjects physics and biology.

Keywords: *crosscutting concept, cause-effect thinking, learning effects*

INTRODUCTION

Many national and international research projects have been carried out to investigate and to improve the quality of science education. For example the Programme for International Student Assessment (PISA). PISA monitors outcomes of international education systems in terms of student achievements, within a common internationally agreed framework (OECD, 2013). This framework was created by PISA in 1997 and adapted to new educational developments by PISA when necessary. This educational framework describes knowledge and skills which all students should acquire at a specific moment in education. Besides the framework of PISA, there are other educational frameworks for science education that aim to improve student achievements. In the United States educational researchers have developed a framework called: K-12 Science Education framework. "The framework highlights the power of integrating understanding the ideas of science with engagement in the practices of science and is designed to build students' proficiency and appreciation for science over multiple years of school" (National Research Council, 2012, p. xi). In the Netherlands, the Ministry of Education, Culture and Science (OCW, 2012) commissioned the Dutch institute for curriculum development (SLO), to develop a curriculum framework for lower secondary science and technology education in the Netherlands (Ottevanger et al., 2014). The curriculum framework that was developed is called *Kennisbasis natuurwetenschappen en technologie voor de onderbouw VO,* which will be referred to as `Kennisbasis´ from here onwards.

The Kennisbasis was developed to guide schools and teachers in the improvement of lower secondary science education by elaboration of the core objectives and in this way give direction to a coherent science curriculum, which facilitates learning progression to upper secondary education. Besides a more coherent science curriculum, the Kennisbasis aims to develop domain-specific metacognition. This interdisciplinary coherence and domain-specific metacognition is considered essential, because it allows students to become more aware of the similarities in different contexts and in different subjects (Boersma, Bulte, Krüger, Pieters, & Seller, 2011; Thijs & Van den Akker, 2009). Students should be prepared for engaging in interdisciplinary science, because currently scientists are often involved in multidisciplinary problems. The purpose of the Kennisbasis is to improve students' achievements in an international perspective (PISA) and in higher secondary education. In addition, the Kennisbasis also aims to contribute to a better orientation on the science and technology profiles at the end of lower secondary education (Ottevanger et al., 2014) Finally, the Kennisbasis also provides many opportunities to encourage and shape talent development.

The Kennisbasis describes the science subjects biology, chemistry, physics, physical geography and technology in terms of three dimensions: core ideas, crosscutting practices and crosscutting concepts. The core ideas describe the knowledge students should have in each disciplinary area. These core ideas originated from the previously developed guideline *Leerplan in Beeld* and have been adapted to the Kennisbasis (Ottevanger et al., 2014). Crosscutting practices describe the skills scientists and engineers need in their daily work (Ottevanger et al., 2014). Crosscutting concepts are scientific concepts that have common applications in science and technology and are therefore interdisciplinary. These interdisciplinary concepts can be used to show students the consistency between the different science and technology subjects. These core ideas, crosscutting concepts and principles are adapted from the *K-12 Science education framework* (National Research Council, 2012a) and *Next Generation Science Standards* (NGS) (National Research Council, 2012b). The addition of crosscutting principles and crosscutting concepts to conceptual knowledge is new for the Dutch curriculum.

At this moment the Kennisbasis describes a curriculum with core ideas, crosscutting concepts and practices, but there are no tested practical guidelines on how to translate these three dimensions into educational material. To examine how this translation should take place, a follow-up project has been started. In this project several science teachers participate in teacher design teams (TDTs). A TDT is defined as "a group of at least two teachers, from the same or related subjects, working together on a regular basis, with the goal the (re)design a enact (a part of) their common curriculum" (Handelzalts, 2009). In close cooperation with the Freudenthal Institute at Utrecht University and several TDTs, SLO developed some examples of science education material that is based on the guidelines of the Kennisbasis (the three dimensions). Teachers who participate in the TDTs tested the developed material in their own lessons and exchanged lesson experience afterward in the TDTs. In this testing the focus was on whether students understood the assignments and were interested. No systematic data were collected about the lesson, student results and student experience. To evaluate to what extent the activities in the designed educational material are effective to stimulate students in the use of crosscutting concepts and crosscutting practices, the examples of science education material need to be evaluated. Therefore, this study will focus on the evaluation of the learning effects of the educational material based on the guidelines from the Kennisbasis natuurwetenschappen en technologie voor de onderbouw VO. The central question of this study is:

- What are the learning effects of explicitly teaching the crosscutting concept cause-effect thinking in lower secondary science education?

In order to answer the central question, three sub questions are formulated:

- How should cause-effect thinking be taught so that students are able to recognize and apply this crosscutting concept in a new situation?
- How far supports the implementation of the crosscutting concept cause-effect thinking in biology and physics education?
- Is the crosscutting concept cause-effect thinking in the subject physics different than in the subject biology? If so, what differences do teachers and students see?

Outcomes of this study can help to define characteristics of educational material that are adequate in improving students' use of crosscutting concepts. Knowledge of these characteristics means the experimental educational material can be modified and tested again. Analysis of the implementation of the Kennisbasis is important, as the intentions of the curriculum developers (the three dimensions) should be reflected in the teaching materials developed (DeBarger, Choppin, Beauineau, & Moorthy, 2013). Without studying the effects of the educational material it is not clear whether and how the ideas presented in the Kennisbasis can contribute to improving learning results and interdisciplinary as well as domain-specific metacognition. Besides these practical relevancies there is also a theoretical relevance of this research. The TDTs try to create educational material that will teach students domain-specific metacognition. But little is known about which learning strategies are effective in this respect. When these strategies for teaching materials are created based on the guidelines from the Kennisbasis, the teaching strategies can be applied in other fields.

THEORETICAL FRAMEWORK

Curriculum

The Kennisbasis is a curriculum guideline. A curriculum is defined as a plan for learning (Taba, 1962). This general definition must be elaborated in order to distinguish different kinds of curricula . Thijs and van den Akker (2009) distinguished curricula on different levels and representations (Thijs & Van den Akker, 2009). There are five different levels of curricula: supra, macro, meso, micro and nano (figure 1).The Kennisbasis is a curriculum guideline which can be classified on the macro curriculum level and influences the lower levels meso, micro and nano. This means that the Kennisbasis influences the school curriculum, teachers and students. This study will focus on the evaluation on student level of the experimental educational material (made by teachers) and thereby focus on the micro and nano level.

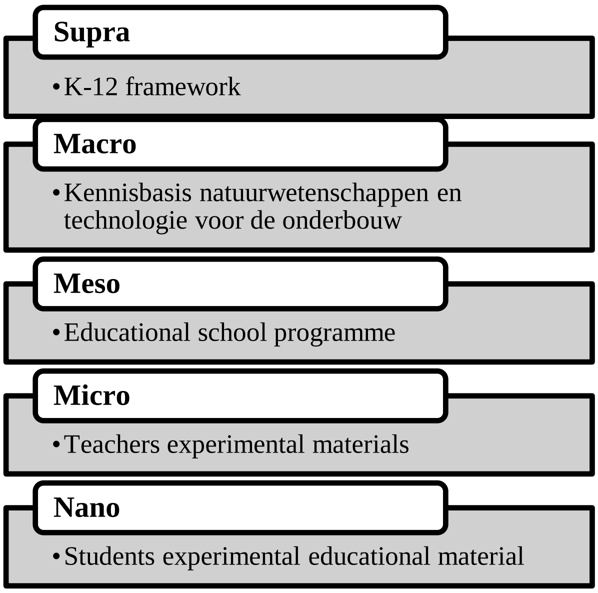

Fig1. Different curricular levels (Thijs & Van den Akker, 2009)

Table 1. Forms of curriculum (Thijs & Van den Akker, 2009)

Intended	Ideal	Vision (rationale or basic philosophy underlying a curriculum)
	Formal/written	Intentions as specified in curriculum documents and/or materials
Implemented	Perceived	Curriculums as interpreted by its user (especially teachers)
	Operational	Actual process of teaching and learning (also: curriculum-in-action)
Attained	Experiential	Learned experience as perceived by learners
	Learned	Resulting leaning outcomes of learners

Beside the differentiation of curriculums on different levels, Thijs and Van den Akker (2009) distinguish different curriculum representations. There are three levels of curriculum forms, all three of which can be divided into two forms (table 1). The Kennisbasis was developed by the SLO commissioned by the OCW. The OCW had a clear and specific vision in mind (ideal level) when they gave the SLO the commission to design the Kennisbasis (formal/written level). In the Kennisbasis the SLO formulated the core ideas more specifically and concretely, implemented a curriculum renewal and had to make examples of teaching materials that meet the guidelines of the Kennisbasis (formal/written level). The next step in which teachers formed TDTs and interpreted the Kennisbasis and develop educational material belongs to the perceived level. The operational level represents the actual process of teaching and learning. The teachers in the TDTs test the developed educational material in school practice. At this point, it is possible to evaluate the developed educational material.

This evaluation can be done by asking students about their learning experiences (experiential) and by testing the learning outcomes of students (learned). The formal/written level and perceived level have already been conducted by Melde Gillissen (2015). She studied the effectiveness of the Kennisbasis in terms of implementation of the Kennisbasis in educational material. This study will focus on the implemented level to attained level, especially on the evaluation (learned and experiential) of the developed educational material in school practice (figure 2). The outcomes of this study can say something about the implementation of the Kennisbasis (formal/written and perceived levels).

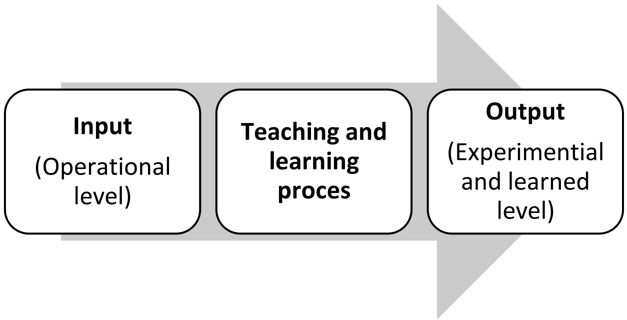

Fig 2. Scheme of evaluation of the developed experimental educational material on the learning experience

The three dimensions of the Kennisbasis: core ideas, crosscutting practices and concepts

The Kennisbasis was inspired by the K-12 Science education framework (National Research Council, 2012a). In this report the National Research Council describes its vision of the main goals of teaching science and technology and how these goals should be achieved. The National Research Council made a framework based on three dimensions: crosscutting practices, core ideas and crosscutting concepts. All three dimensions should be combined to “support students’ meaningful learning in science in engineering” (National Research Council, 2012a). Therefore, these three dimensions need to be integrated in curricula, instructions and assessments. In the Netherlands, the SLO adapted these three dimensions in the Kennisbasis. New for the Dutch curriculum is the addition of crosscutting concepts and crosscutting practices and the use of these crosscutting concepts and practices as a strategy to develop domain-specific metacognition.

The disciplinary core ideas summarise the main and basic ideas of a discipline. The National Research Council considers an idea to be a core idea if it meets at least two of the following criteria:

- “Have broad importance across multiple sciences or engineering disciplines or be a key organizing principle of a single discipline.
- Provide a key tool for understanding or investigating more complex ideas and solving problems
- Relate to the interests and life experiences of students or be connected to societal or personal concerns that require scientific or technological knowledge.
- Be teachable and learnable over multiple grades at increasing levels of depth and sophistication. That is, the idea can be made accessible to younger students but is broad enough to sustain continued investigation over years.”(National Research Council, 2012a, p. 31).

Crosscutting practices are “the major practices that scientists employ as they investigate and build models and theories about the world and a key set of engineering practices that engineers use as they design and build systems” (National Research Council, 2012a, p. 30). So crosscutting practices describe the way scientists and engineers work and think. Examples of crosscutting practices are: model development & model use, research, designing, information literacy, reasoning skills, computational & mathematical skills and appreciating & judging. Experiencing these crosscutting practices helps students to understand how scientific knowledge develops and to reason in a scientific context.

Crosscutting concepts are applicable to all the different domains of science and technology. They describe ways of reasoning that have proved helpful in generating research questions and approaches and providing a deeper insight into science. Examples of crosscutting concepts are: patterns, cause & effect, scale, proportion & quantity, systems & system models, energy & matter, structure & function and stability & change (National Research Council, 2012a). In the Kennisbasis the SLO added two new crosscutting concepts: sustainability and risk & safety.

Domain-specific metacognition

Metacognition was originally defined by John Flavell as "cognition about cognitive phenomena," or more simply "thinking about thinking" (Flavell, 1979, p. 906). This means that students have a sound grasp of their learning process and are able to adapt their learning process with the help of metacognitive strategies (Boekaerts & Simons, 1995). One can only speak of metacognition on condition that students consciously use metacognitive strategies.

"Metacognitive strategies are general skills through which learners manage, direct, regulate and guide their learning" (Brown et al., 1983). Examples of metacognitive strategies are concept-mapping (Novak & Gowin, 1985) and reflection questions (Baird & Mitchell, 1986). These strategies help to construct knowledge and are generally applicable in numerous school subjects. Besides these general metacognitive strategies, there are domain-specific metacognitive strategies. Domain-specific metacognitive strategies are strategies which arise from the perspective of the domain itself. Two examples of domain-specific strategies in the school subject biology, are "ontwerpend leren" (Janssen, 1999) and "systeemdenken" (Boersma, 1997). These two metacognitive strategies are based on characteristics of biological thinking (thinking in designs and thinking in systems) and can help students to achieve metacognition in the subject biology. The subject boundaries are then crossed by the claim that: the metacognition achieved in the subject biology in the form of "systeemdenken", can be used to construct knowledge and skills by students in other subjects (Boersma, 1997).

To get a better understanding of metacognitive strategies we will discuss their characteristics (Boerwinkel, 2003). The first characteristic is that metacognitive strategies are crosscutting concepts and crosscutting practices that help experts to approach phenomena in their daily profession. To approach phenomena experts often use several metacognitive strategies that will not exclude one another but complement each other. Second characteristic is that metacognitive strategies are summarised theories. These theories are usually generally accepted and form the basis of Western science, so we do not see metacognitive strategies as mini theories (Hooykaas, 1976). Another characteristic of metacognitive strategies is that they select certain aspects of reality by their presentation of a question. For instance, you are a schoolteacher and your students have taken a test. From the perspective of a unity & variety metacognitive strategy, you can ask yourself: did all the students score the same? What are the differences in scores? From the perspective of change & continuity, you can ask yourself: did the students who scored badly in the previous test also score badly in the present test? Or did they score differently? And how will the students perform in the next test? From the perspective of a cause-effect metacognitive strategy, you can ask yourself: what causes these differences? And what will be the effect of the differences in scores? So using a certain kind of metacognitive strategy automatically selects a type of questioning that selects certain aspects of reality. A fourth characteristic of metacognitive strategies is that they offer heuristics to gain knowledge about a certain topic or phenomenon. As discussed under the third characteristic, metacognitive strategies go with certain questions. To answer these questions generally applicable strategies can be used. These strategies are called heuristics. Heuristics help structure the thinking process for finding the right answer to a question generated by the metacognitive strategy. A useful heuristic in the cause-effect metacognitive strategy and the form-function metacognitive strategy can be analogy reasoning. The fifth and last characteristic of metacognitive strategies is that they can function as organiser for learning experience from a pre-school child up to and including university education. Children can use metacognitive strategies at a young age in the perspective of form & function by sorting out blocks by colour, form or size. This early use of metacognitive strategies is the starting point for a long learning pathway. A next step can be that students learn to sort out the sorting criteria or that they determine the sorting criteria. During secondary education students can also use the same metacognitive strategy by discussing sorting criteria for the classification of organisms in different kingdoms. In this example every learning experience is helpful for the next learning experience, which helps elaborate the heuristic function of the metacognitive strategy.

In this study cause-effect thinking is seen as a domain-specific metacognitive strategy. In the first place, because cause-effect thinking helps students to think about and if necessary adapt their learning process. Secondly, cause-effect thinking is a crosscutting concept that is applicable to all the different domains of science and technology. So students can learn cause-effect thinking within the domains of science and technology, but they can also apply cause-effect thinking in daily life situations and language school subjects.

Now we know that cause-effect thinking is a domain-specific metacognitive strategy, it is important to know how this strategy should be taught. Many researchers recommend that learning metacognitive strategies should consist of emphasising how the strategies should be used, when they should be used and why students should use them.

When explaining why students should use metacognitive strategies it is important to highlight the value of the particular strategy in order to motivate students to use this strategy strategically and independently (Cross & Paris, 1988; Kramarski & Mevarech, 2003; Schneider & Lockl, 2002; Schraw, 1998). To acquire metacognition it is also important, rather necessary, that students communicate about their learning, thinking and acting. This can be done by collaborative methods and regular moments of reflection. These moments of reflection are necessary to raise awareness among students of what is actually learned. During these reflection moments students think about if the new knowledge can be related to prior/already present knowledge, if the new knowledge is useful and which tasks were expected from them (Baird, 1986). It is very important to link the reflection to the use of the metacognitive strategy, because it enables the students to see what the use of the strategy will provide them. Research also shows that it is desirable to vary in reflection methods, otherwise reflection might become a boaring and useless to students (White & Gunstone, 1989).

As mentioned before, crosscutting practices and concepts can show connections between the different science domains. This connection between different science domains will only be visible for students when teachers make these concepts and practices explicit for students. This can be seen as a strategy to develop domain-specific metacognition in biology education (Boerwinkel, 2003). An example of this can be found in the link between technology and biology teaching. In technology teaching, students learn to design solutions based on the demands based on the desired functions, in other words reasoning from function to form. In biology the same reasoning can be applied in 'designing' an animal that can survive in specific climatic and ecological conditions. The metacognitive strategy learned for a particular subject, in this case technology, can help students to construct knowledge in another science subject or context (Boersma, 1997). Boerwinkel (2003) shows in his thesis the importance of questioning in the development of metacognition. When students start asking questions about a certain phenomenon, crosscutting concepts and practices can be helpful both for formulating questions from a specific perspective and to teach students where to start looking for an explanation for these questions (Boerwinkel, 2003). It is important that teachers guide students in the development of metacognition. This can be done by telling students explicitly which crosscutting concept or practice is being used in a lesson and which characteristics of this crosscutting concept or practice are important. If a teacher has previously used the crosscutting concept or practice now being taught, it is useful to refer to that lesson, for example by asking what characteristics were then discussed in class and what are the similarities and differences with this lesson. In addition, a teacher should take into account four criteria formulated by Boerwinkel, Waarlo and Boersma (2009). They formulated criteria for an effective learning and teaching strategy. The strategy should:

- "Invite students and teachers to verbalise their thoughts
- Invite students to reflect on the way they generate knowledge
- Include different realistic contexts and stimulate transfer amongst them
- Include a small and recognisable nucleus of content that can be used as a growing representation of the perspective" (Boerwinkel, Waarlo, & Boersma, 2009, p.13)

Assessing metacognition has challenges. For example, metacognition is not directly observable in students (Sperling et al., 2002). To assess metacognition researchers try to find methods to make metacognition observable, like self-report methods and thinking-aloud techniques. Weaknesses of these techniques and methods are that they rely too heavily on verbal ability & writing skills of students and do not notice implicit cognitive processes. Beside the fact that metacognition is not directly observable, metacognition is also a very complex construct (Schraw & Moshman, 1995). Metacognition involves cognitive knowledge and cognitive regulations, which both can be divided into subclasses, and is also liable to affective and motivational states.

In this study metacognition is assessed by using the Van Oers criteria (1987) and the six categories of Hennessey (1999). In 1999 Hennessey developed six categories to characterise various levels of metacognition (table 2). Statements made by students derived from classroom observations will be categorised using the Hennessey categories. A brief description of the Van Oers criteria is given further on in the theoretical framework.

Table 2. Six categories of Hennessey that describe various levels of metacognition.

Category	Category description
1. Conceptions	This category includes any metacognitive statements in which the student is engaged in considering his or her conceptions of the content in question
2. Reasoning	This category includes any metacognitive statements in which the student refers to the reasoning used to support his or her conceptions.
3. Implications	This category includes any metacognitive statements in which the student is explicitly considering the implications or limitations inherent in his or her conceptions.
4. Thinking Process	This category includes any metacognitive statements in which the student is explicitly considering his or her thinking or learning process as an object of cognition.
5. Status	This category includes any metacognitive statements in which the student is commenting on the status of conceptions (i.e., explicitly commenting on the intelligibility, plausibility, and fruitfulness of the conception under consideration).
6. Conceptual Ecology	This category includes any metacognitive statements in which the student refers to or specifically uses any components of his or her conceptual ecology.

Cognitive apprenticeship, scaffolding and transfer of knowledge

An educational learning strategy in line with the approach where on the one hand students construct knowledge and on the other hand teachers equip students with tools for learning in social and cultural learning activities is the strategy of cognitive apprenticeship. Cognitive apprenticeship is characterised by: teacher demonstrates specific skills, students think out loud, scaffolding, learning takes place in a practice context and regular reflection and feedback moments (Collins et al., 1989 & Boerwinkel, 2003).

The first step of cognitive apprenticeship is modelling. In this phase the teacher demonstrates the knowledge or skills to be learned. The teacher tells or shows the students the skills or knowledge to be learned and simultaneously thinks out loud about the cognitive thinking steps taken. During modelling it is very important that the teacher makes his cognitive thinking steps explicit and comprehensible for students.

When it is clear to students what is expected of them, students are ready to go to the next phase of cognitive apprenticeship: coaching. In this phase students explore and try out the skills and knowledge with the help and support of the teacher. During this phase the teacher provides less and less help, support and control. To know what support teachers should give to students, it is important that teachers know which cognitive processes occur in students in practice. By letting students think out loud while practicing the knowledge or skills, cognitive processes will be visible for teachers. This makes clear which conceptions, thoughts and ideas students have. So based on these conceptions, thoughts and ideas the teacher can adapt their teaching (Driver, 1988). Another advantage of letting students think out loud is that students are forced to put thoughts and actions into words and explain these thoughts and actions. In this way, students are encouraged to express their own reasoning in language, making the students' concepts easier to handle (Van Oers, 1987).

At a certain point, students do not need constant support, but have to be supported by for example help questions and checklists. This third phase is called scaffolding. Scaffolding is a form of help that is adapted to the student, which reduces over time and which is focused on the transfer of responsibility to the student (van de Pol, Volman & Beishuizen, 2010). To apply scaffolding in class, Janneke van de Pol and her colleagues developed a four-step plan (Ruiz-Primo & Furtak, 2007; Van de Pol, Volman, & Beishuizen, 2012). The first step is to determine the position of the students through diagnostic strategies. Where in the learning process is the student and what are his/her needs? The next step is the diagnosis check during which the teacher checks if the diagnosis is correct. The third step of scaffolding consists of giving help. This help can be given via open questions, feedback or instruction. The kind of help given by the teacher is adapted to the student needs and goals (Vigotsky's zone of proximal development). The final step of this model of scaffolding is to check if the help that is given by the teacher has resulted in the student reaching Vigotsky's zone of proximal development. If the student successively reached his/her zone of proximal development, a new zone of proximal development will arise. This new zone of proximal development is likely to be of a higher level.

The last step of cognitive apprenticeship is to use the knowledge or skill in a new context. Cause-effect thinking is taught in a school setting, but should also be applicable in the context of daily life. The school and everyday life of students appear to be separate cultures. Students that have learned skills and knowledge in one culture rarely apply learned skills and knowledge in the other culture. For dealing with meaningful situations outside school, the student will usually not draw on the knowledge and skills gained in school, but will use the knowledge and skills gained outside school. A feature of knowledge acquired outside school is that learning and acting are strongly tied together, but are difficult to use in another context. This phenomenon is called situated learning (Hennessy, 1993). For a good application-oriented acquisition, cause-effect thinking should be taught in different contexts, but for a good transfer of knowledge, cause-effect thinking should not only be applicable in one context but in different contexts. This can be achieved by teaching cause-effect thinking in a variety of situations, so that cause-effect thinking is not only linked to one context (Simons & Verschaffel, 1991). Important for a good transfer is that students are encouraged to communicate in spoken and written language about cause-effect thinking. Communicating explicitly about cause-effect thinking is the first step to isolate cause-effect thinking from the learned context. This will make cause-effect thinking applicable in other contexts.

Criteria of Van Oers (1987)

Van Oers sees conceptions as a repertory of action capabilities and he states that students should have a conceptual understanding of concepts. According to Van Oers it follows from this that a theoretical conception should also be practically applicable in for example problem solving. In this way of thinking, cause-effect thinking can be seen as a concept.

In his dissertation, Van Oers examined characteristics of students' behaviour which could be seen when students had acquired a good conceptual understanding of a particular concept. This has ultimately resulted in the four criteria of Van Oers:

- Generality of reference
- Systematic
- Idiomatic
- Consciousness

Generality of reference signifies that students can use the concept in different contexts, other than the context in which the concept is learned. Not all concepts are automatically applicable in different contexts. Generality of reference needs to be acquired by for example practicing the same concept in different contexts. The second criterion is systematic. When concepts are used correctly according to the rules and on the correct object, the student is able to use the concept systematically. Van Oers describes idiomatic as that students are able to communicate about the concept. This means that the concept and the content of the concept must be translated from actions into language. So students should be able to talk about the application of the concept, should be able to reason about the concept, and make decisions within the concept etcetera. The last characteristic of Van Oers is consciousness. Consciousness signifies that a student is aware of his/her ability to use the concept and reflect on the concept. Using the concept consciously means that students act in accordance with the rules and regularities of the concept, deliberately organise and control their own actions based on rules and regularities of the concept.

Cause-effect thinking can only be used by students when they are aware that they are using cause-effect thinking. Students should use cause-effect thinking consciously as a strategy and see the applicability of this strategy in a wide range of phenomena and contexts. In addition, students should also be able to know the content of the concept and should be able to reason within cause-effect thinking. These criteria are in line with the criteria of Van Oers and the six categories of Hennessey (table 2). The categories of Hennessey and the criteria of Van Oers show similarities. If students belong to the higher categories of Hennessey, they will also fit the criteria of Van Oers. In this study the six categories of Hennessey will be used as evaluation criteria to assess whether students use cause-effect thinking as a metacognitive instrument. This choice has been made because the categories of Hennessey are described in more detail and therefore more usable for analysis and the categories of Hennessey indirectly comprise the criteria of Van Oers. (Boerwinkel, 2003; Van Oers, 1987)

Causal reasoning

Causal reasoning is one of the most important and basic cognitive processes that underpins all higher-order activities such as conceptual understanding and problem solving (Jonassen & Ionas, 2008). To understand all scientific domains, it is essential for students to be able to reason causally. Causal reasoning enables students to predict, infer, and explain events or phenomena that they encounter and observe (Hung & Jonassen, 2006), all of which are skills needed for conceptual understanding and problem solving.

The Kennisbasis also formulated some learninggoals for students regarding lessons in which cause-effect thinking is explicitly taught (Eijkelhof, in preparation):

- Distinguish cause and effect in phenomena
- Relate cause and effect to each other
- Distinguish cause-effect relations and correlations
- Predict phenomena in nature, science and technology based on knowledge of mechanisms
- Recognize that phenomena could have more than one cause and/or effect.
- Indicate the probability of cause-effect situations
- Distinguish questions that ask to a function or cause
- Using mechanisms to explain patterns
- Describe mechanisms on different organisational levels
- Search systematically for causes of failing systems
- Think critically about statements about cause and effect

Causality is the relationship between a cause and its effect(s). A cause is an "incident or action which, in the presence of those conditions that usually prevail, made the difference between the occurrence or non-occurrence of the event" (Copi, 1978, cited in Schustack, 1988). A cause-effect relationship is a cause-effect relationship when it satisfies the following three principles: priority principle, covariation principle (also known as co-occurrence or probabilistic principle) and mechanism principle (also known as explanationist principle) (Ahn, Kalish, Medin, & Gelman, 1995; Bullock, Gelman, & Baillargeon, 1982; Kelley, 197; Thagard, 2000). The priority principle states that a cause is always prior and contemporary to the effect(s). "When an effect is attributed to one of its possible causes with which, over time, it covaries" (Kelley, 1973, p. 108). This statement describes the covariation principle. This principle states that when a cause-effect relationship occurs just once, this cause-effect relationship is not legitimate. So the cause-effect relationship should occur on repeated occasions and the cause and effect should clearly be associated with each other. The last principle which a legitimate cause-effect relationship should meet is the mechanism principle. This principle describes the causal chain often seen in causal relationships. In a causal chain the main cause and effect are related to each other by consecutive events. So the mechanism principle connects the main cause and effect by the underlying causal chain. Causal reasoning is mostly studied in the two principles mentioned last: the covariation principle and the mechanism principle (Ahn, Kalish, Medin, & Gelman, 1995; Thagard, 2000). Both principles are necessary to understand the causal relationship. Educational research has shown that students who are able to make a correlation (covariation principle) between two variables using statistical models will not automatically be able to explain the mechanism (mechanism principle) that shows how and why the covariation occurs (Hedstrom & Swedberg, 1998; Mahoney, 2001). So in order to teach students causal reasoning it is important to provide students with activities from the mechanism principle and the covariation principle.

In this study the focus will be on the mechanism principle. Good methods to visualise the complexity of causal reasoning are influence diagrams. "A teacher demonstrates specific skills, students think out loud, scaffolding, learning takes place in a practice context (Howard & Matheson, 1989) is a visual display form for depicting causal relationships among the variables in complex phenomena and simulating the underlying mechanism that governs the relationships (Hung & Jonassen, 2006, p. 1604)". In an influence diagram the most important variables are identified: the main cause and effect and all the variables that will connect the main cause and effect to each other (causal chain). In an influence diagram the causal chain is very important, because this can help students to visualise and explicitly describe the causal structure of a phenomenon (Shapiro, van den Broek, & Fletcher, 1995). In this study influence diagrams are called cause-effect schemes, abbreviated CES.

In 2004, Pessoa de Carvalho & Paulo studied how pupils in the first years of primary school (between seven and ten years old) build op causal explanations in physics. They found that students construct their own causal explanations by following a sequence of four stages (table 3). The four stages of Pessoa de Carvalho and Paulo can also be seen as levels of explanations. The levels of explanation offered and received were found to be significantly related to learning. So the higher the level of causal explanation, the more students have learned about the content and causal reasoning. As can be seen in the table, the types of questions asked by the teacher are also important to achieve a certain level of causal explanation. So asking appropriate questions and giving clear explanations are critical. Graesser, Baggett and Williams also found in their research that asking questions is one of the most essential cognitive components that guide human reasoning. By asking questions teachers can focus the students' attention on for example parts of the influence diagram that need attention or are difficult to find out. In order to answer these kinds of questions, students must have a sound grasp of how each component of the cause-effect relationship relates to other components of the causal relationship. So the real challenge for teachers in guiding students getting acquainted with causal reasoning is to ask the right questions at the right times.

Tabel 3 The four stages of causal explanations by Pessoa de Carvalho and Paulo

Level/phase of Construction of causal explanations	Behavioural objective and action	Type of questions asked by teacher
Arousal of awareness	Reconstruct actions and observations	Questions of "what...?" or "when ...?" to establish a common memory
Making connections	Establish links between personal or other pupils' actions and the reactions of apparatus (or spreadsheet or visual model)	Questions of "Why ...?" or "How...?"to establish a common interpretation
Disassociation	Relate connections or links made to objects' physical attributes and respective results	Direct attention to object by asking "What if ...?" to establish a common explanation
Conceptualisation	Elaborate links to old "learnings" and "knowings" including accounting for novelties in the observed phenomena	Change the context by asking "Would this ...?" questions to establish a common understanding

METHOD

This study is a qualitative study of the learning effects of students who have had lessons which explicitly taught cause-effect thinking. Not all aspects of cause-effect thinking will be explicitly taught. The following aspects of cause-effects thinking will be investigated:

- Distinguish cause and effect in phenomena
- Relate cause and effect to each other
- Recognize that phenomena could have more than one cause and/or effect.
- Describe mechanisms on different organisational levels
- Think critically about statements about cause and effect

Research design

This research will focus on the evaluation of learning effects of students who have had lessons which explicitly taught cause-effect thinking. In preparation for evaluating the learning effects, several phases of preparation will be completed (figure 3).

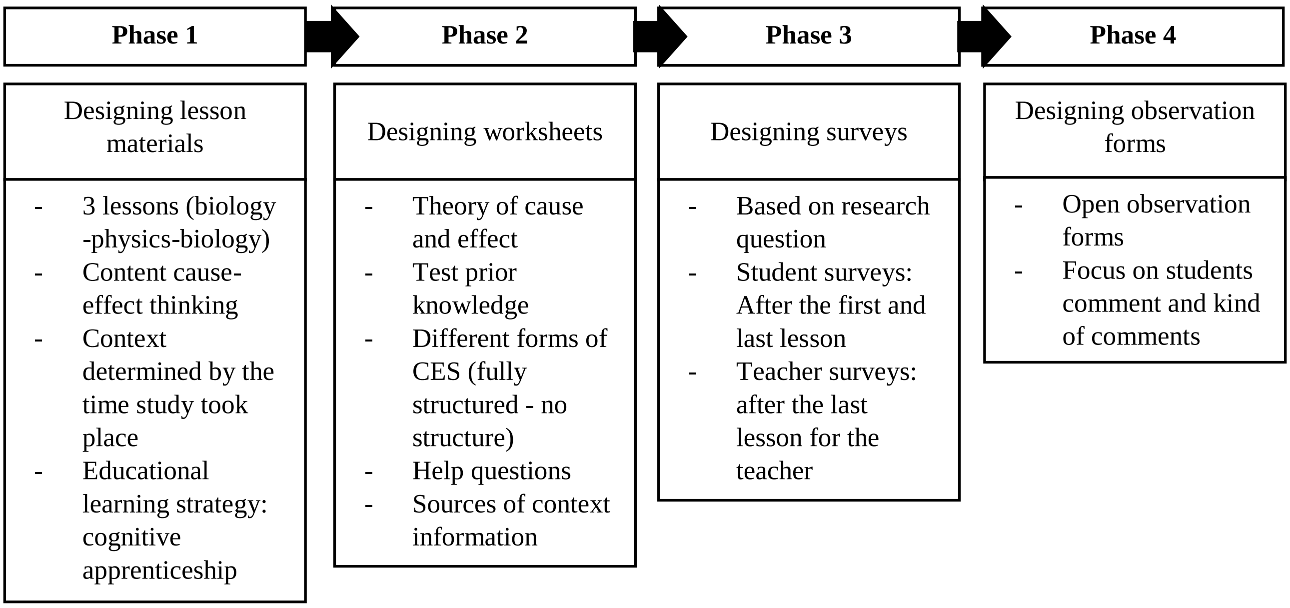

fig 3. Phases of preparation

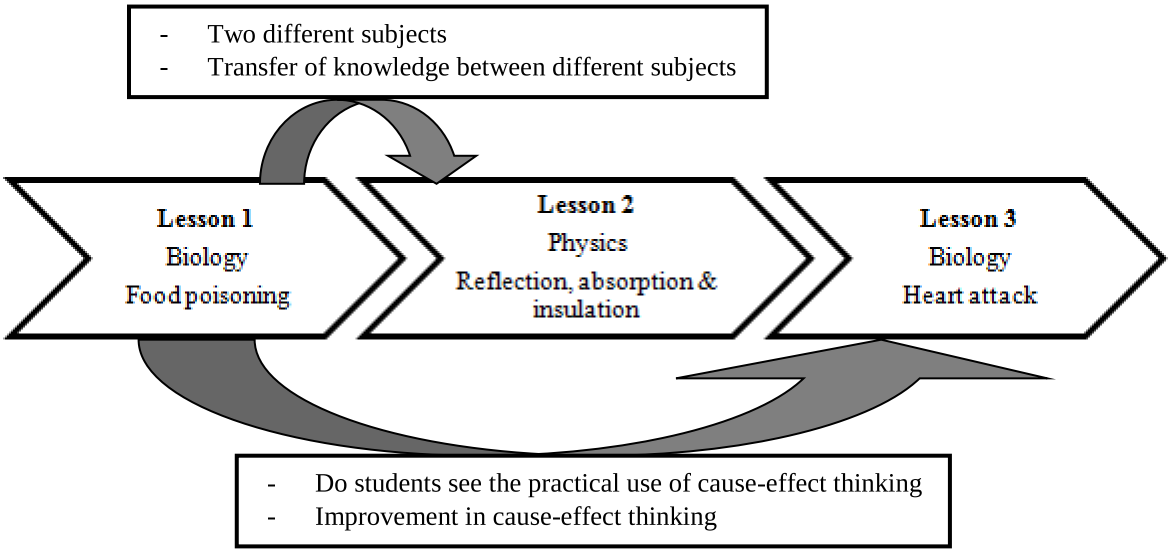

Fig 4. Overview of the three lesson designed in this study

The first phase of preparation is designing lesson material in which cause-effect thinking is taught explicitly. The content of the lesson was determined by the time period in which the data collection had to take place (October 2015 - November 2015) and the teachers who were willing to cooperate in the current study. One physics teacher and two biology teachers were willing to cooperate in this study, so the school subjects are biology and physics. There were three lessons designed in which cause-effect thinking is explicitly taught (figure 4), because two lesson in different subjects are needed to say something about the transfer of knowledge and skills between different subjects (two lessons). In addition, the improvement in cause-effect thinking should be examined in the same subject (one lesson). There could be more lessons about cause-effect thinking, but the amount of time limited the number of lessons that could be developed, taught and analysed. Because the author is specialised in biology education, two lessons were designed for the school subject biology and one lesson was designed for the school subject physics. The author's specialism also determined the order in which the lessons were taught. The first and last lessons were on the subject biology and the second lesson was on the subject physics. The context of the lessons in which cause-effect thinking is learned, was determined by the time in which the lessons took place. This is an important condition to fulfil, because the Kennisbasis claims that acquiring crosscutting concepts and crosscutting practices does not take extra time. According to the Kennisbasis crosscutting concepts and crosscutting practices can be learned in the context of the teaching material of the current curriculum. Teachers were asked to send their time schedules for the period between October and November 2015 and their exercise book. During biology classes teachers and students use the method: Biologie voor jou, handbook 2a, havo/vwo, zesde druk. During physics classes teachers and students use the method: NOVA, leeropdrachtenboek, klas 1 & 2 havo/vwo, vierde editie. During the time of this study the students were working on a chapter about nutrition and digestion in the subject biology and on a chapter about sound in the subject physics. For each of the three lessons, the chapter was searched to find an appropriate subtopic for the cause-effect classes. In this search it was important that the subtopic fitted in with the crosscutting concept cause-effect thinking. For each subtopic a draft was made of a possible lesson. In consultation with the teacher the most appropriate subtopic was selected. In addition, the teachers were asked if they had specific lesson elements that they would like to see in the lessons or lesson material. The teachers had no preferences for what the lessons and lesson materials should look like. This gave the researcher no restriction in the development of the lesson materials.

Beside the determination of the context in which cause-effect thinking should be taught, the way in which cause-effect thinking should be thought also needed to be defined. Cognitive apprenticeship was chosen as educational learning strategy, because this learning strategy fits in with cause-effect thinking. Cognitive apprenticeship fits in with cause-effect thinking because this educational learning strategy has the following characteristics: teacher demonstrates specific skills, students think out loud, scaffolding and learning takes place in a different practice context. Furthermore, cause-effect thinking is seen as a domain-specific metacognitive strategy. From the theoretical framework it turns out that learning metacognitive strategies should include emphasising how the strategies should be used, when they should be used and why students should use them. Also regular moments in which students communicate about their learning, thinking and acting are important. During these moments of reflections students should think about if the new knowledge can be related to prior/already present knowledge, if the new knowledge is useful and which tasks were expected of them. The visual representation of cause-effect thinking is determined by researching on how to teach causal reasoning. As described in the theoretical framework this study will show cause-effect relations as cause-effect schemes, abbreviated as CES and described in the literature as influence diagrams.

When all the lesson materials were finished, the teachers were instructed on how to teach the lesson and what the critical phases of the lessons are.

Going back to the first research sub question, we have to define what a new situation is in this study. A new situation can be seen in two ways: as a different type of situation and as a different learning task for students. In this study we have a new situation because we change subjects (biology - physics - biology) and we change the context in which cause-effect thinking is learned (food poisoning - reflection, absorption and insulation - heart attack). A new situation can also be created by using different learning activities and different thinking steps. In this study we did not use a large number of different learning activities. In all the lessons, students made a CES and in the second lesson students also carried out an experiment and wrote a recommendation. During the first lesson, students did not make many thinking steps on their own, because the CES was fully structured and all the different cause-effect relations were given. In the second lesson, students had to carry out considerably more thinking steps, because only the first cause is given in a semi-structured CES. In the last lesson, students had to carry out most of the thinking process by themselves. Students were only given a question to start with. After some minutes of training, the teacher discussed the main cause and effect so students did not lose too much time. So over the three lessons the number of thinking steps differed; from almost none at the beginning to a complete thinking process at the end.

The second phase of preparation was making worksheets to collect students' answers. For the first biology lesson, worksheets consisted of:

- Theory about how to make a CES and which symbols are used
- Theory about different sorts of cause-effect relations
- Theory about what happens inside the human body during food poisoning (text and/or movie)
- Two questions that test the prior knowledge of students about cause-effect relations
- Three questions that gradually scaffold students to fill in a fully structured CES

After making the worksheets for the first biology lesson a hypothetical learning trajectory was made (annex 1) (HLT). A shortened version can be seen in table 4.

Table 4. Shortened version of the hypothetical learning trajectory for the first lesson.

Lesson element	Most important teacher and student activity, hypothesised learning result and elements of learning cause-effect thinking
Introduction to research	- Introducing observer - Explaining data collection
Introduction to subject	- Students share experience with food poisoning - Students complete assessment 1 so they have a clear and workable understanding of a cause-effect relation - Students complete assessment 2 so they understand the difference between a cause-effect relation and a relation that will happen over time
Description of food poisoning	- Students complete assessment 3 so they know what the symptoms of food poisoning are (also starting point for CES) - Explain assessment 4 & 5
Working on assignment	- In assessment 4 students determine all the different components/boxes of the CES, so students realise that they first need to define the different cause-effect relations of the CES - In assessment 5 students fill in a fully structured CES in which they fill in the given CES components/boxes. Students have the opportunity to add their own empty boxes and alter the structure of the CES if they want. In this way students put the right cause-effect relations together
Discussing assignment in class	- By discussing the CES on the blackboard students develop a toolkit which they can use the next time they make a CES. This toolkit consists of a step-by-step plan about how to make a CES, a range of questions students can ask themselves, the knowledge about which possible building blocks a CES can be made up of and how students can use these building blocks
Complete survey	- Students fill in a digital survey

For the second lesson, in the subject physics, worksheets were also constructed. One worksheet was constructed as homework assignments. This worksheet consists of:

- A description of the overall assignment and the associated context in which students will be acting (text and movie)
- Theory about reflection, absorption and insulation
- Three basic questions about cause-effect relations in reflection, absorption and insulation that will help students in class to make a CES
- Two practical assignments in order to grease the wheels during physics class; install a decibel meter on your phone and a link to a sound clip

A second worksheet was made to use during physics class. This worksheet was less theoretical, less structured, more practical and consisted of three parts:

- CES:
    - Description of the CES assignment and some help questions to help students with constructing the CES
    - Three less structured CESs; one for each theory described in the homework assignment (reflection, absorption and insulation)
- Experiment
    - Table to fill in the results of one of the experiments
- Exchange:
    - Table to fill in the results of the different experiments
    - Three less structured CESs

For the second lesson a HLT was also made (annex 1) after completing the worksheets. A shortened version can be seen in table 5.

Table 5. Shortened version of the hypothetical learning trajectory for the second lesson.

Lesson element	Most important teacher and student activity, hypothesised learning result and elements of learning cause-effect thinking
Introduction to research	- Introducing today's programme - Showing timetable
Discuss homework assignment in class	- In the homework assignment students determine main cause and effect (end and beginning of the CES). - Students understand the processes reflection, absorption and insulation - Students know the first cause and the last effect of the CES
Experiment and making CES	- Students fill in a more open CES (if necessary with help questions) - Students experience which materials have the biggest effect on the volume - Student experience and know the characteristics of the materials that have the biggest negative impact on the volume
Exchange practical results	- Students exchange their practical results
(Writing recommendation)	- Students need to combine the information from the CES and the results from the experience to write a recommendation on how to minimise the sound pollution in their residence. Students need to communicate the information by writing about cause-effect thinking. In this way teachers can check for two of the criteria of Van Oers and can say something about cause-effect thinking as a metacognitive strategy
Complete survey	- Students fill in a digital survey

For the last lesson in the subject biology, only a source was created. This source describes the causal relation between eating a lot of food that contains saturated fat and a heart attack. This means that students were not given a structured CES or any help questions on a worksheet. As for the first two lessons, a HLT for the third lesson was also made (annex 1) after completing the source about the higher risk of a heart attack after eating food that contains a lot of saturated fat. A shortened version of the HLT for the third lessen can be seen in table 6.

Table 6. Shortened version of the hypothetical learning trajectory for the third lesson

Lesson element	Most important teacher and student activity, hypothesised learning result and elements of learning cause-effect thinking
Introduction to research	- Introducing today's programme - Showing timetable
Videos	- Students watch and listen to videos in which they see the process of today's context of cause-effect thinking
Making CES	- Central question in making CES: why do you have an increased health risk if you eat too much food that contains saturated fat? - Students make a fully open CES (from post-its). Together with teachers and peer students, they determine the first cause and the end effect.
Class discussion	- Students examine, discuss and think critically about their CES in comparison with the CES on the blackboard, so that they know that there are different methods of making a CES, but that the questions you ask yourself are always the same - Students fine-tune their toolkit - When asked what can be done to prevent a heart attack, students have to read their own CES, pick out the right information to answer this question and formulate this answer in understandable language. So students apply their CES to answer a question
Complete survey	- Students fill in a digital survey

All the worksheets are included in annex 2.

The third phase of preparation of this study consisted of making surveys for students and teachers. After the first and last lessons, a digital survey was conducted during class. After each teacher's last lesson, they were interviewed. The surveys and interview questions are included in annex 3.

The last phase of the preparation was making observation forms. For all three lessons the same observation forms were used. The observation forms are all very open and focus on the kind of comment students make during the lesson. In a large table, the kind of comment and the comments themselves were written down every five minutes. In this study four different kinds of comments were distinguished: comments that ask for clarification, comments on the experience of students, comments on the biology or physics subject (context in which cause-effect thinking is learned) and comments from students about cause-effect relations and the CES. A shortened version of an observation form can been found in annex 4.

Participants

The participants in this study were 61 students at the Pius X College (annex: Aalderinkshoek) in Almelo (The Netherlands). The author knows this school because she went to this school as a student and also did her internship at this school. The students who participated were in eighth grade of HAVO (age:14-15) and divided into two classes: 2B and 2C. Class 2B consisted of 31 students, of which 15 were males and 16 females. Class 2C consisted of 30 students of which 12 were males and 18 females.

The teachers who participated in the study were one physics teacher and two biology teachers. The physics teacher was a woman aged 52 and she had five years of experience as a teacher. The first biology teacher was also a woman, aged 33, and she had been a teacher for 12 years. As well as the qualification to teach biology, she was also qualified to teach physical education. The second biology teacher was a 23-year-old woman (=researcher) who had then taught biology for one year. These teachers were asked to participate in this study, because they were open-minded and willing to try out new lesson materials.

Data collection and analysis

Data collection took place during the three lessons, which were taught in October and November 2015. All the lessons were recorded with a video camera. During the lessons the students filled in the worksheets and after the lesson the worksheets were collected and stored for analysis. The first two lessons were observed by the author herself, but during the last lesson a peer student from the researcher carried out the observations because the author was giving the lesson. This peer student was informed properly on how to make observations and how to fill in the observation forms.

Analysing data from the surveys was mostly done by calculating percentages of students from the total number of students. Information from the CESs was analysed in three ways. First all the CESs were analysed by counting the number of students (%) that made a CES with a certain number of boxes. This analysis also incorporated the number of wrongly used boxes. Secondly, all the CESs were analysed by counting for each box of the CES the percentage of students that used that cause-effect relation in their own CES. In this analysis, the number of students that wrongly used a cause-effect relation was also incorporated. The last way in which the CESs from the last biology lesson were analysed was by using the six categories of Hennessey (table 7). Other information collected from the observations (mostly comments by students) was also categorised using the six categories of Hennessey. Table 7 was used to say something about the level of metacognition that students reached at the end of the three lessons. The table is divided into four columns. The first gives names to the six different categories of which a general description is given in the second column. The last two columns describe student statements and student actions in the form of making a CES and have been adapted to this study. Answers to survey questions, statements made by students during the lessons and recorded on film or in observations and the CES were classified into the adapted six categories of Hennessey. Another rater also classified the statements and CES, so the inter-rater reliability could be determined using Cohen's kappa.

Table 7. The six categories of Hennessey adapted to the study

Category	Category description	Description of student statement	Description of CES
1. Conceptions	Statements from students which refer to their own thinking. Statements from students that prove that students can describe their own thought and that students are aware of the thinking of peer students	Students mention separate elements of the CES. Students mention that they use cause-effect thinking	Students use only separate boxes/cause-effect relations in the CES without connections to other boxes/cause-effect relations
2. Reasoning	Statements from students that prove that students are able to explain why they are thinking something	Students explain their conceptions. Students use connecting elements between separate cause-effect relations. Students are able to explain the CES	Students use connecting elements (arrows between boxes) in their CES
3. Implications	Statements from students that indicate that students can explicitly consider the potential strengths or weaknesses of their conceptions and statements that provide evidence that students are aware of the possible limitations of their conceptions. Statements that prove that students can consider what errors or positive effects may result when their concepts are applied in a new situation	See category description	Students are able to make a distinction between HDL and LDL in the CES and are able to reason consistently with this distinction. Students are able to apply the CES and see the practical use
4. Thinking process	Statements from students which prove that students are able to reflect on their own thinking and learning process	Statements from students which indicate that they will use cause-effect thinking or make a CES again. Statements from students which indicate that cause-effect thinking and making a CES is a useful strategy to solve problems or learning method. See category description	Students make a CES that shows more information than the information that is given by the teacher and information source
5. Status	Statements from students which show that students take their own ideas aside and compare their ideas with ideas from peer students. Students analyse these ideas and based on this analysis possibly modify or improve their own ideas	Students ask critical questions about the content of cause-effect thinking. See category description.	It is not expected that CESs from students will be found in this category
6. Conceptual Ecology	This category includes any metacognitive statements in which the student refers to or specifically uses any components of his or her conceptual ecology.	It is not expected that statements from students will be found in this category.	It is not expected that CESs from students will be found in this category.

RESULTS

The results section of this study is divided into two parts. The first part consists of results organised by lesson. This first section will consider per lesson how the lesson is taught and what the most important results are (students' answers to worksheets, CES, observations). In the next section, the results will be considered per research question. The results in this second section will consist partly of the answers of students to the survey questions and partly of the observations from the lessons.

Results Section 1

Lesson 1

How the first lesson about food poisoning was planned can be seen in table 4 and in annex 1. The HLT was followed, but the discussion in class got off to a slow start. During the introduction of the subject food poisoning, students came up with the following comments when the teacher asked about experience with food poisoning:

"That the food is no longer edible." "Wrong food, the food is poisoned." "That means that you are allergic to some kinds of food." "The food is no longer edible, because it was prepared in the wrong way." "The date before which the food should be used has passed, because of this the food is full of bacteria" "A lot of bacteria are on the food"

The last two statements from students that refer to bacteria and food were used by the teacher to introduce food poisoning and today's assignments. During the discussion from assignment 1 in which students were asked what the words cause and effect make them think of, the following answers were given:

"Action-reaction. Something has happened. When there is a reaction to this action, is it a cause-effect relation. For example in the subject History. The Second World War established Europe." "Something has happened, which causes another activity. The second activity is the effect. For example: when I do something wrong, I will be punished. Doing something wrong is the cause; the effect is getting a punishment."

Assignment 2 asked students to determine which of the two given examples is a good example of a cause-effect relation. Both students who answered the question started with excluding example 1 and then explaining why example 2 is a good example of a cause-effect relation:

"Example 1 is not an example of cause and effect because nothing happens there. It just happens when time goes by. Example 2 does not happen when time goes by, but is a reaction to an action, so this is a cause-effect relation." "Example 1 is not an example of cause and effect, because it is a fact. I do not see a how-how connection. Example 2 is an example of cause and effect, because there is action-reaction. The cause is pushing the button; effect is that the television turns on."

Reactions from students to assignments 1 and 2 show that students are able to recognise a cause-effect relation. The answers to assignments 1 and 2 show that students are able to explain why they think something. Therefore these statements belong to the second category of Hennessey.

In assignment 3 students were asked to describe the symptoms of food poisoning. Students did not have any questions about the assignment and used source 1 to find the right answer to the assignment.

Assignment 4 was done by many students by shading the different cause-effect relations. Some students did not do this assignment because they had already seen the structured boxes from the CES on "het knipblad".

During the observations from assignment 5 two different methods of working were seen (figure 5 and figure 6). The majority of students (about 75%) started making their CES by filling in the symptoms of food poisoning. Next, these students went to the beginning of the CES and filled in the empty CES boxes from left to right, and ended up where they started. This method of working can be seen in figure 5. The other students also started their CES by filling in the symptoms of food poisoning. Contrary to the other method of working, these students filled in the box directly to the left of the symptoms. In this second method of working students filled in the CES from the right side of the CES to the left side of the CES, see figure 6. Some students were asked why they filled in the CES in the way they did. Students from both methods of working answered: because I think this is the most logical procedure. Students were also asked about the position of the question mark. Students from both methods of working gave the same answer: because the position in which it currently stands, was the position that was left over. So students placed the question mark at a place that was left over (in figure 5 and 6 step 6) and did not think about the meaning of the question mark. Answers from students to these two questions show that students are able to describe their own thought and therefore function in the first category of Hennessey. Some other observations were that none of the students used an empty box and added a cause-effect relation to the CES and just one or two students were able to fill in the condition box (red box in figure 5 and 6). Students had a lot of questions about the condition box. The teacher answered those questions by referring to the theory about cause-effect relations.

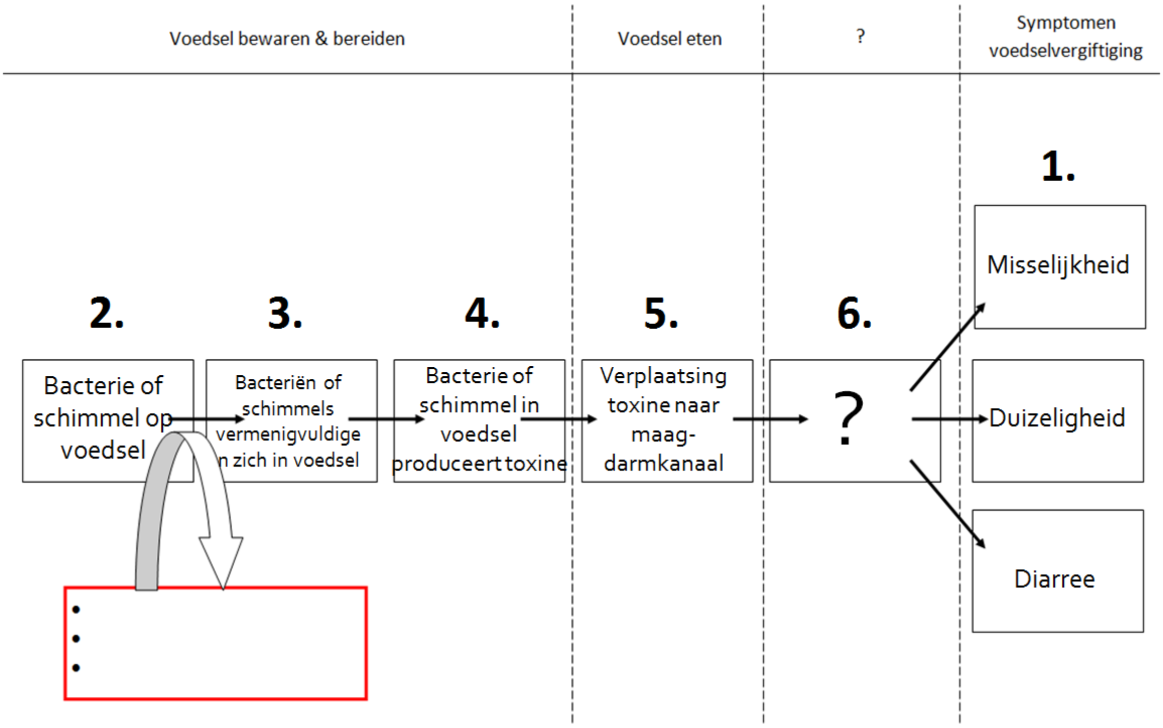

fig 5. First method of working by students

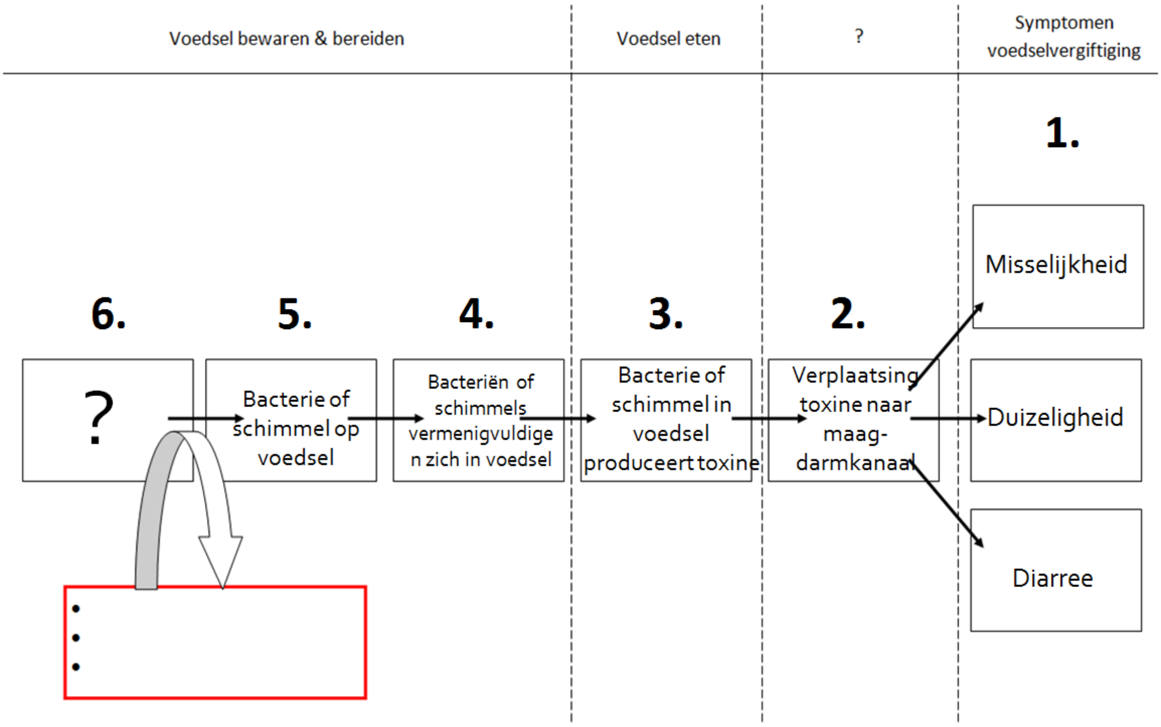

fig 6 Second method of working by students

The next phase of the lesson contains a group discussion about the CES and the process of making a CES. The discussion was started by the teacher by asking students to describe the term toxin. Some students searched the internet to look up the term during assignment 5 and came up with a description from Wikipedia:

“Toxins are generally speaking all the toxic substances and belong follow the principles of toxicology"

After asking the student to give a description in his own words, the following response was made:

“Toxic substances are produced by bacteria and fungi and do no good to your digestive system”

Other students did not search for the term toxin but got the meaning of the term from the source about food poisoning:

“Substance that is able to duplicate itself and is made by bacteria and fungi. A toxin causes food poisoning.”

After giving a description of the term toxin, the teacher showed the correct CES on the television screen (figure 7), because she did not know what to do to get the discussion started. Also the amount of time that was left for this lesson was limited.

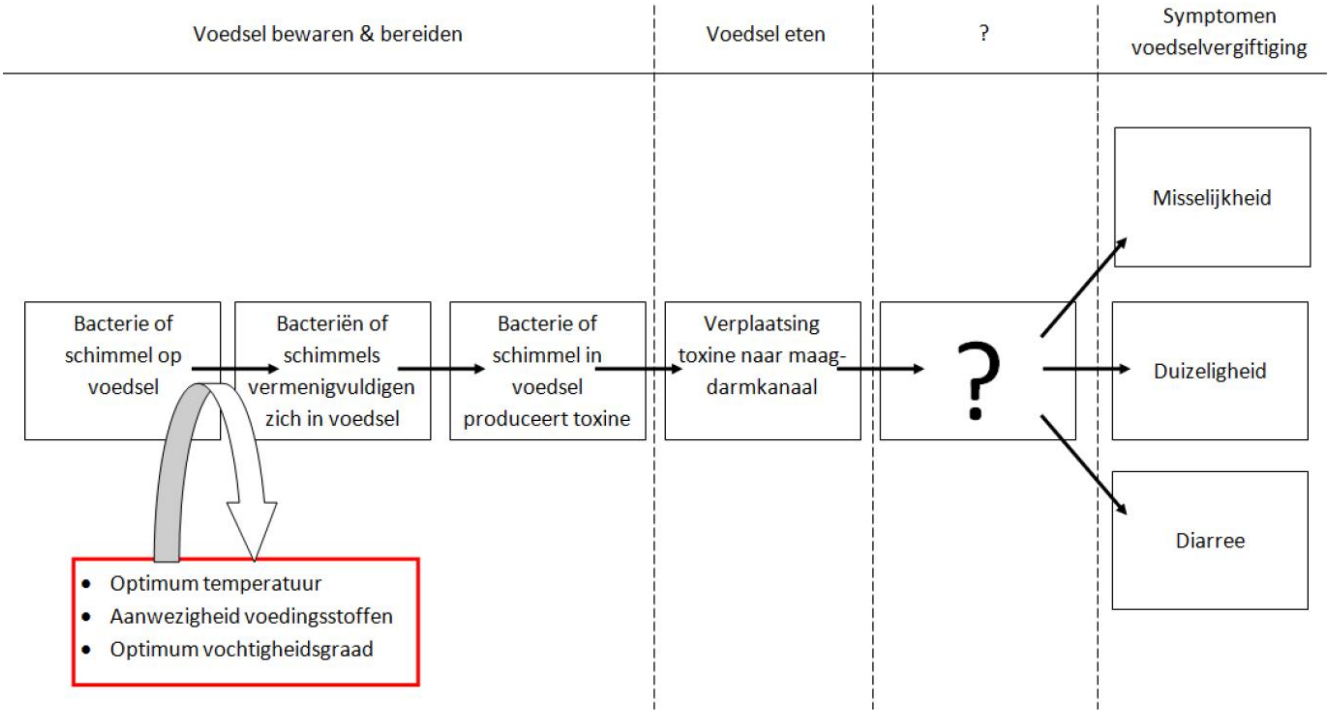

Fig 7. The correct CES of the first biology lesson about food poisoning

Teacher explained figure 7 and asked students how they made their CES. The answers of students to this question are in line with the observations that can be seen in figure 5 and 6. This shows that students function in the first category of Hennessey, because they are able to describe their own thought. Then, the teacher discussed the condition box by asking students what they filled in in their condition box and why they did it that way. These questions from the teacher were not answered by the students. In class 2b the following conversation took place:

Teacher (T): *“What does this box mean?”*
Students (S): -
T: *“Those bacteria from the first box are not a threat for your body when there are just a couple of them. Those bacteria cause problems when there are a lot of bacteria. To go from one bacterium to a lot of bacteria, bacteria have to duplicate. Do bacteria duplicate under all circumstances?”*
S: *“No, only when the circumstances are good.”*
T: *“Alright, what are in this case good circumstances?”*
S: *“Moisture, temperature and?”*
S: *“Food!”*
T: *“Well done. So to get a lot of bacteria from just 1 bacterium, the circumstances have to be ideal. Bacteria have*

to have a sufficient amount of food and the temperature and amount of moisture have to be perfect for the bacteria."

In class 2c the following conversation took place:

T: *"What does this box mean?"*
S: -
T: *"Okay, I suggest that we read together line 3 up to and including line 6. Luuk?"*
S: *"Before these toxins are made, bacteria and fungi multiply in food. This multiplication only happens under certain circumstances: your body must have the right temperature, there has to be sufficient food and moisture."*

T: *"Okay, thank you. Who can tell me what we have to fill in in the condition box?"*
S: *"Moisture"*
S: "Food*"*
S: *"Temperature between 35°C and 40°C"*

After this discussion about the condition box, the teacher asked a couple of students to explain the CES in his and her own words. In both classes students were able to explain the CES, but students used words like "first", "second", "after that" et cetera. Words like, "cause" "effect" "is caused by" "results in" et cetera were not used by students in their explanation. Again, when students are able to explain their thought about their CES, students function as described in the first category of Hennessey.

To finish off the lesson in class 2b, the teacher gave a short summary about food poisoning ending with the symptoms of food poisoning. One of the symptoms is diarrhoea. She asked students why diarrhoea is dangerous for us humans. Students were able to answer this question and respond with the answer dehydration. In class 2c the lesson ended with the following discussion:

T: *"Is there someone who would like to say or ask something?"*
S: *"Due to high temperature, bacteria die. So by cooking food, food poisoning can be prevented. Right?"*
T: *"Yes very good, that is correct."*
S: "*How is it possible that we get food poisoning?"*
T: *explains about uncooked meat, the importance of washing your hands before preparing food and food safety.*

This last discussion shows that students are able to apply the CES that they made. Therefore this discussion can be categorised in the third category of Hennessey.

From the discussion about the condition box and the end of the first lesson, it can be seen that students are able to apply cause-effect thinking. Students are not able to apply the crosscutting concept fully independently, but with help from the teacher they can answer questions in which cause-effect thinking is needed to give an answer.

Lesson 2

How the second lesson about reflection, absorption and insulation was planned can be seen in table 5 and in annex 1. In general the HLT was followed, but the discussion about the homework and making the CES was not taught according to the HLT. The homework assignment was not made by most students, so the teacher spent more time discussing the homework assignment. She discussed the three processes: reflection, absorption and insulation. Also the main cause and effect were determined in class for each of the three processes. The extra time spent on the homework discussion was at the expense of the time planned for the experiment & making CES and making a start with writing a recommendation. Because students did not do the homework assignment, students found it difficult to make a CES and asked a lot of questions while making a CES. Some of these questions show that students function as described in the first category of Hennessey. Questions from students were:

- *"What should I do?"*
- *"How many boxes does this CES contain?"*
- *"What is the beginning of the CES? And what is the end?"*
- *"What is the cause? And what is the effect?"*
- *"Is this correct?"*

During the phase in which students made a CES some students highlighted parts of the information source on reflection, insulation and absorption. On inquiry it appeared that students highlighted only parts of the information that they thought were important and useful for making a CES.

During the experiments, students used all the different insulation, absorption and reflection materials and described the materials in detail. During the experiment, students did not refer to the CES and did not use words like “cause” and “effect”. Most of the conversations were about the allocation of tasks between the students, proper functioning of the decibel indicator, position of the insulation, absorption and reflection materials in relation to the decibel indicator and sound source, outcomes of the decibel indicator and discussion between students about which material was the best insulation, absorption or reflection material.

After making a CES and collecting data from the insulation, absorption or reflection experiment students exchanged practical results. During this exchange students talked very enthusiastically about which material muffled sound the best and what this material looked like. Colour, texture, hardness and elasticity were discussed by students during the exchange. When explaining absorption some students also referred to their own living room or bedroom at home. These statements prove that students are able to reflect on their own thinking and learning process and apply knowledge about cause-effect thinking. Therefore this discussion belongs to the third and fourth category of Hennessey. The following is an example of a discussion between two students:

Student 1 (S): *“Have you ever painted your bedroom?”*
Student 2 (S2):*Yes, last summer holiday I painted my bedroom together with my dad.”*
S1: *“Did you then strip your bedroom?”*
S2:*”Yes, I cleared it out totally. We not only painted my room, but I also got new carpet and new curtains.*
S1: *“Do you remember that the sounds in your room sounded very loud and hollow without any furniture?”*
S2: *“Yes, I can remember that. But what has this to do with absorption?”*
S1: *“Curtains, carpet and your furniture absorb sound. When this is all out of your bedroom, the sounds sound louder and more hollow. “*
S2: *“Aaah, alright. So furniture, carpet and curtains absorb sound. Therefore all noise sounds less noisy in a full bedroom compared to a bedroom that is cleared out.”*

After this lesson about insulation, absorption and reflection, students had to hand in a recommendation for the local council about the noise pollution and possible solutions to bring down the noise pollution (annex 2, “Opdracht advies schrijven”). After analysing the recommendations it turned out that all students were able to:

- write a recommendation in which they explained at least three solutions to reduce noise pollution
- write a recommendation with a logical structure
- show results from the experiments in a well-organised way
- make a CES on insulation, absorption and reflection and show them in a well-organised way

As in the lessons, some students used words like “cause”, “effect”, “because” and “through” in their recommendation, but most students did not use words like that. Instead of that, students used words that indicate a certain order (“after”, “then” “at first” etcetera). Students were not able to show their solutions in their CES, whereas they were able to explain their solutions in words. Finally, the discussion also shows that students are able to recognise a cause-effect relation and some students started to apply cause-effect thinking (highlighting parts of source to use in CES, asking questions that refer to cause-effect thinking and asking about the number of separate cause-effect relations).

The CESs were also analysed (fig. 8 and fig. 9). Figure 8 shows the number of students (expressed as a percentage of the total number of students) with a certain number of cause-effect relations or number of boxes in their CES. The black parts of the bars of the histogram represent the number of students (expressed as a percentage of the total number of students) that used a cause-effect relation wrongly in their CES. From figure 8, it can be seen that students were able to make a CES that consists of three to ten cause-effect relations of a total number of twelve cause-effect relations. A little less than 15% of the students made a CES that consisted of 3 cause-effect relations and a little less than 10% of the students made a CES that consisted of 10 cause-effect relations. Most of the students (about 40%) were able to make a CES that consisted of five cause-effect relations. It was expected that the more separate cause-effect relations in a CES, the higher the number of errors. In figure 8, it can be seen that this is not the case. About 10% of the students were able to make a CES that consisted of ten cause-effect relations and they did not make any mistakes in making connections between separate cause-effect relations in the CES.

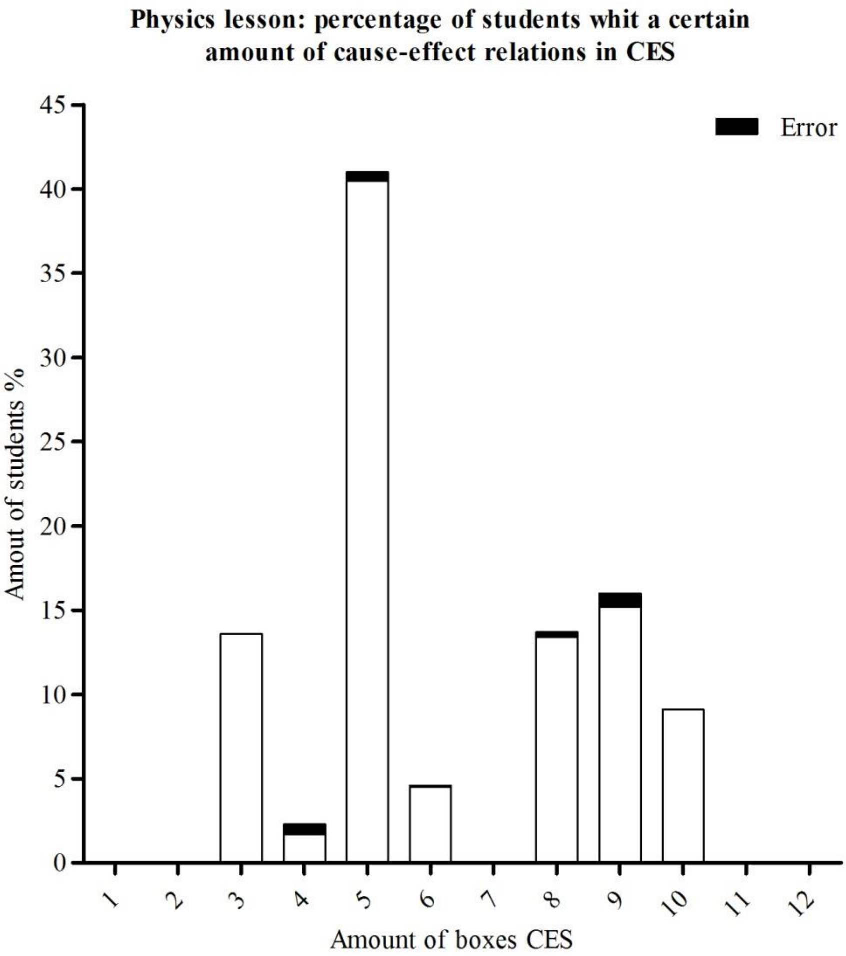

Fig 8. The number of students with a certain number of components in a CES.

Figure 9 shows the level of difficulty per cause-effect relation or per box of the CES. In annex 5, it can be seen which box number represents which cause-effect relation. The histogram shows the number of students (as a percentage of the total number of students) who used a certain cause-effect relation (referred to as box number). The black parts of the bars of the histogram represent the number of students who wrongly used a certain cause-effect relation. From figure 9, it can be seen that box 7 and box 8 are the two most difficult cause-effect relations in the CESs. Box 7 and box 8 both belong to the CES of the process absorption. Box 7 stands for: sound vibration from the sound pollution transform absorption material. Box 8 stands for: heat generation. In annex 5, it can be seen that box 7 and box 8 are both effects of the same cause. All students who made a mistake in box 5 supposed that the sound vibrations changed shape as a result of touching absorption material. The opposite is the truth; the absorption material transforms shape as a result of contacting the sound vibration from the sound pollution. Students who made a mistake in box 8 all thought that as a result of loss of energy as sound vibration, heat was generated. In reality, both the production of heat and the shape transformation of the sound vibrations resulted in a loss of energy for the sound vibrations. Furthermore it is remarkable that box 10 (box ten represents a question mark) was not used by any student in their CES.

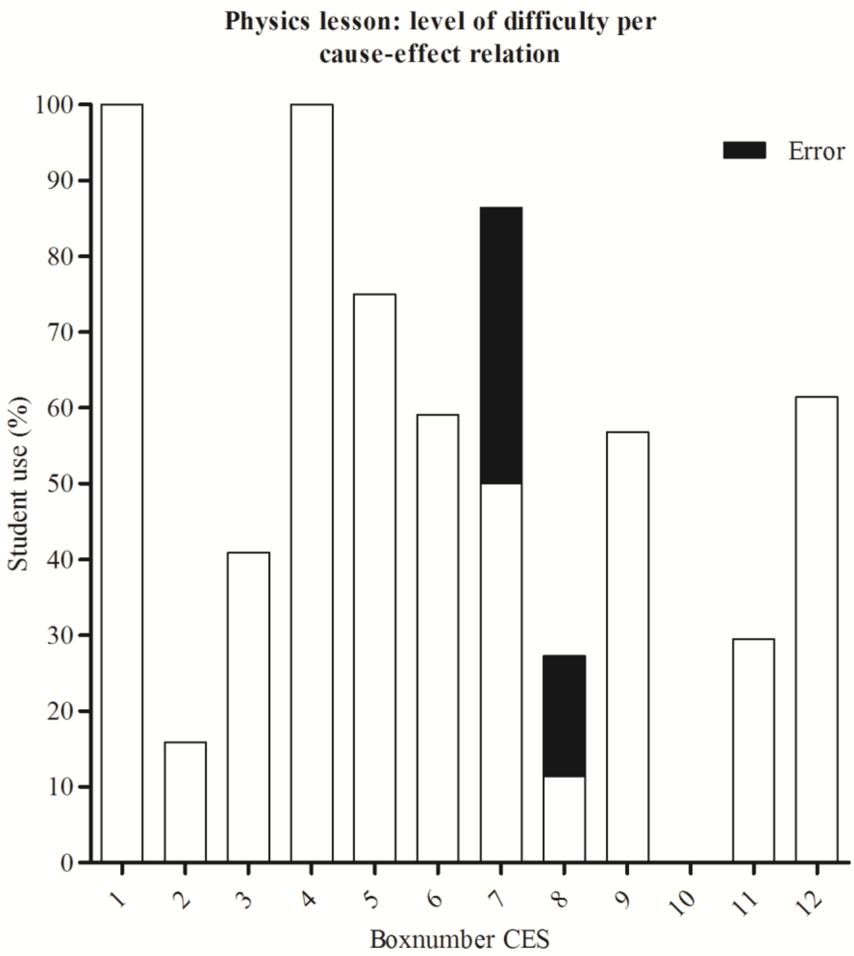

Fig 9. Level of difficulty per component of the CES.

Figure 10 and figure 11 show two examples of a CES made by a student.

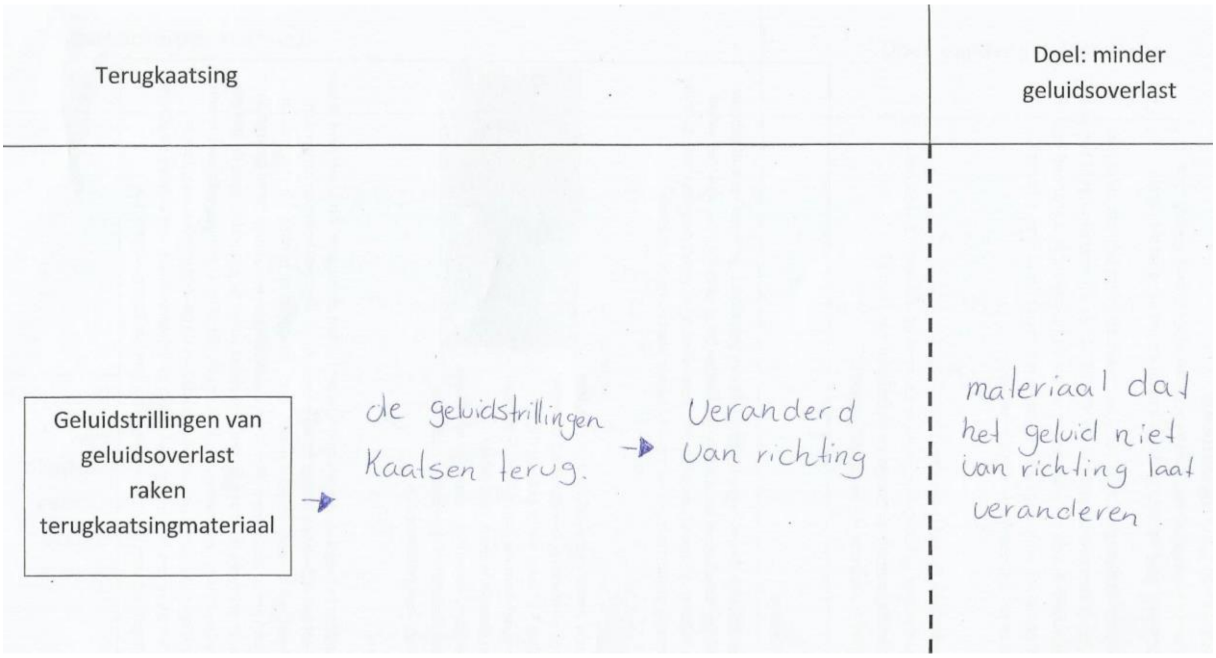

Fig 10. An example of a CES made by a student

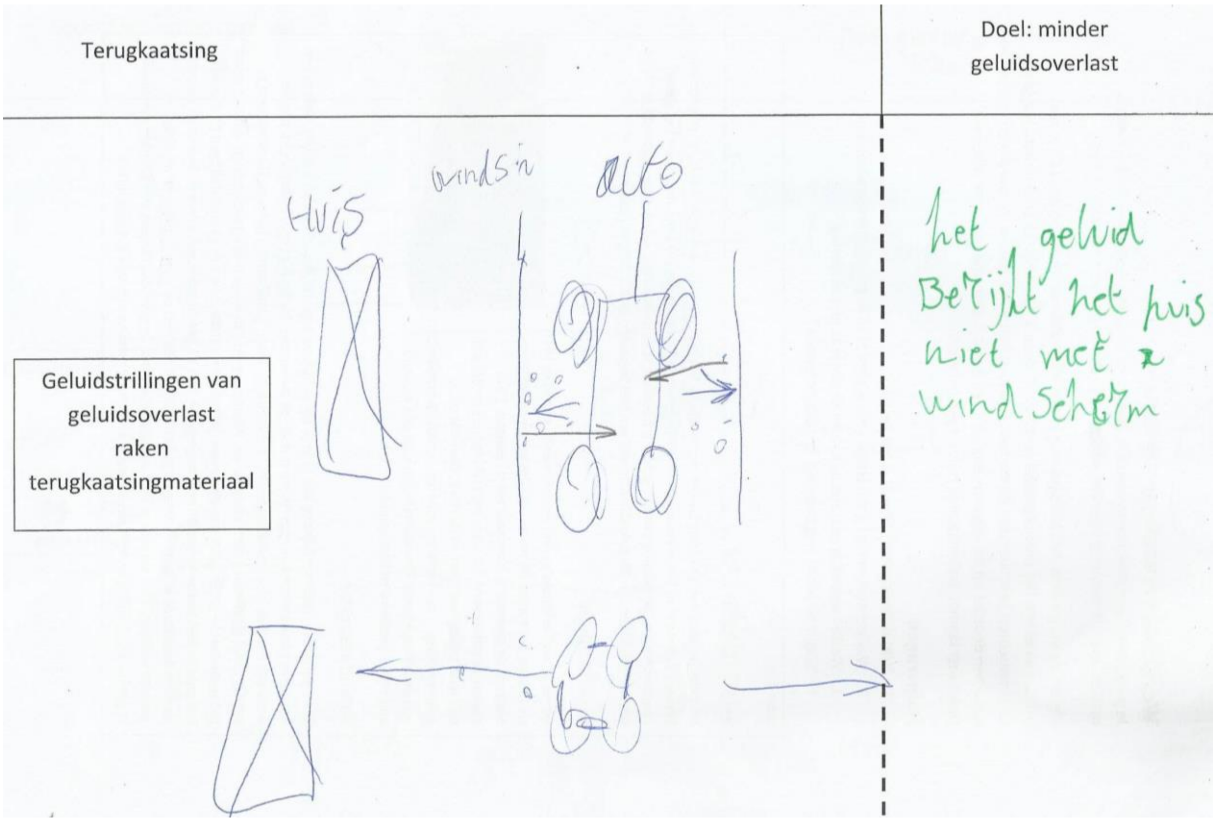

Fig 11. An example of a CES made by a student

Lesson 3

In table 6 and annex 1, it can be seen how the second biology lesson about a heart attack was planned. The lesson was taught as planned in the HLT. During the introduction of the lesson, which explained what was expected of the students during this lesson, a lot of students responded in something like the following way:

"Oh I understand, we have to make a CES about how you can get a heart attack. This time we will use a CES in biology."

This statement can be categorised in the first category of Hennessey.

Instead of showing two videos, only one video was shown in class. The hyperlink of the video was given to students so that they could watch the video if they liked.

So to start with making the CES, the teacher asked students: "What happens when you get a heart attack?" The following conversation took place (the following discussion represents what happened in class 2b and class 2c):

S: *"At that moment, your heart does not get any blood supplied."*
D: *"Alright, good answer. How is this possible? So, what is the cause of the interruption of the blood supply?"*
S: *"I have no idea?"*
D: *"Okay, can somebody help?"*
S: -
D: *"Okay, suppose we read source 1 together."* Teacher pointed out student to read source 1.
D: *"Okay, thank you. Let's see if we are able to answer the question. Question was: what is the cause of the interruption of the blood supply?"*
S: *"That is because a blood clot closes the coronary artery."*
D: *"Yes, very good. What we discussed is a part of the end of the CES. This is not the end, but you will be able to finish the CES. Let's have a look at the beginning of the CES. How does the CES start? Or, what is the cause of a heart attack?"*
S: *"Eating unhealthy food and much too little exercise."*

D: *"Yes, you are very close. Let's have a look at source 1 and look for a more specific description of "unhealthy food."*
S: *"Oh, it is food that contains a lot of saturated fat."*
D*: "Yes, very good! Now we know the end of the beginning of the CES, your job is to figure out what happens in your body when you eat a lot of food that contains saturated fat and how this can cause a heart attack. I will put the boxes of the CES that we figured out together on the blackboard. You can use your own post-its to make the CES complete."*

Parts of this discussion show that students are able to reflect on their own thinking and learning process and apply knowledge about cause-effect thinking. Therefore this discussion belongs to the third and fourth category of Hennessey.

After this discussion students started to make a CES in pairs. A lot of students read source 1 and highlighted parts of source 1 they wanted to use in their CES. Some students wrote the highlighted text down on paper and connected the different parts with an arrow. Just a few students asked for the number of boxes or separate cause-effect relations. As in the first biology lesson, students used different methods of making their CES. The difference between the first biology lesson and the second biology lesson was that for the second biology lesson a wider variety of methods were used by students. Some student pairs started at the beginning of the CES and reasoned from cause to effect. Some student pairs worked the other way around and started with the effects and ended with determining the cause. There were also students who did not use words to make a CES, but made little drawings on the post-its. Most students used one post-it for one box or separate cause-effect relation, but some students used several post-its for one cause-effect relation or did not use the post-its structure at all. While making observations, a lot of pairs discussed the part of source 1 and their CES about HDL and LDL. As in the physics lesson, students did not use words that refer to cause-effect thinking but they used words that refer to a specific order.

After half an hour, one student pair was asked to put their CES on the blackboard. The CES on the blackboard was discussed in class by discussing each CES box. In both classes box 1, 2 and 3 were placed in the right order and connected to the right causes and effects. In class 2b the following discussion took place:

D: *"Does the intake of fat result in less digestion of cholesterol?"*
S: *"No, we don't think so. In our CES we have that fat is digested in two kinds of packages: HDL and LDL."*
D: *"Very good. If you eat a lot of food that contains saturated fat, is your HDL level or LDL level high?"*
S: *"You get a low HDL level."*
D: *"Okay, good. And LDL?"*
S: *"Your LDL level is high."*
D: *"Perfect, very good."* In the meantime the teacher placed the boxes in the right place on the blackboard.
D: *"What is the effect of a high LDL level in your blood?"*
S: *"LDL forms a deposit on the wall of the coronary artery."*
D: *"Alright, we are close. Your answer is further on in the CES and is not a direct effect of a high LDL level in your blood."*
D: *"What is the function of LDL?"*
S: *"It causes a high level of cholesterol in your blood."*
D: *"Yes, you are close, but this is also not a direct effect of a high LDL level in your blood."*
D: *"I have here two boxes about the transport and function of LDL."*
S: *"Oh you mean the transport to the liver."*
D: *"Yes, that's correct. Have a look at the men with wheelbarrows in source 1. What are the LDL wheelbarrows doing?"*
S: *"They are putting sand down."*
D: *"Okay, good. Let's have a look at the boxes. Which one would you place with LDL?"*
S: *"A lot of transport of cholesterol to the liver and other parts of the body."*
D: *"Yes, very good. A high LDL level in your blood causes a lot of transport of cholesterol to the liver and other parts of the body."*
D: *"Let's try to look at the HDL part in the same way."*
S: *"That has to be: less transport of excess cholesterol to the liver."*
D: *"Yes, that's correct. Very good."*
D: *"I will put the rest of the CES on the blackboard, because this lesson is almost over. In the meantime you will think about solutions to prevent a heart attack. You can use the CES to help you think about a solution."*

D: *"Okay, who could come up with a solution?"*
S: *"Maybe you can change your diet. You should eat more food that contains HDL and less food that contains saturated fat and LDL."*
D: *"Yes, perfect solution and something you can easily start with."*
D: *"Name x used the boxes of the CES to come up with a solution. Can somebody else think of another solution?"*

S: *"Yes, maybe you could remove the plaque with a medicine or surgery?"*
D: *"Yes, also a good solution. You used the CES in a very smart way. As you can see, you can intervene in this scheme at at least three places to reduce the risk of a heart attack."*
S: *"Miss, I have a question. Can you not simply work out more?"*
D: *"Yes that is true. You can also work out. This working out will affect the LDL level of your blood. By working out, you lower your LDL level."*

In class 2c the following discussion took place (box 1, 2, 3, 4 and 7 placed correctly):

D: *"Alright, the CES is correct up to and including a high LDL level and a low HDL level. What is the effect of a high LDL level and a low HDL level?"*
S: -
D: *"Does a high LDL level automatically cause a heart attack?"*
S: *"No."*
D: *"Alright, which cause-effect relations are in between?"*
S: *"A high LDL level forms a deposit on the wall of the coronary artery."*
D: *"Alright, we are close. Your answer is further on in the CES and is not a direct effect of a high LDL level in your blood. "Okay, due to the amount of time that is left, I'll put the correct CES on the blackboard. In the meantime you can fill in the survey."*

From both discussions, it can be seen that students from both classes found the same part of the CES difficult. This part consists of box 4, 5, 6, 7, 8 & 9 and is about the difference between HDL and LDL. From both discussions, it can be seen that the teacher asked students a lot of how and what-questions and also explicitly used words that refer to cause-effect thinking. Both discussions also showed that students are able to reflect on their own thinking and learning process and apply knowledge about cause-effect thinking. Therefore these discussions belong to the third and fourth category of Hennessey. The discussions also show that students are able to recognise a cause-effect relation and some students from class 2b are able to apply cause-effect thinking. In order to answer the question from the teacher about possible solutions to reduce the chance of a heart attack, students needed to apply cause-effect thinking or the CES on the blackboard.

As in lesson 2, all the CESs were analysed (fig. 12 and fig. 13). Figure 12 shows the number of students (expressed as a percentage of the total number of students) with a certain number of cause-effect relations or number of boxes in their CES. The black parts of the bars of the histogram are marked as "Number error". This black part represents the number of students (expressed as a percentage of the total number of students) that did not make a difference or did not make the right difference between a little HDL (box 4) and a lot of LDL (box 7). Also students who did not mention (the right) amounts in further reasoning about LDL and HDL (box 5, 6, 8 & 9) were counted as "number error". The red parts of the bars of the histogram are marked as "Reasoning error". This red part represents the number of students (expressed as a percentage of the total number of students) that did not correctly use a cause-effect relation in their CES. So these students made a wrong connection between separate cause-effect relations in their CES and connected boxes to each other that are not part of the same relation. From figure 12, it can be seen that students were able to make a CES that consists of one or three to twelve separate cause-effect relations or boxes of a total number of nineteen cause-effect relations. A little less than 5% of the students made a CES that consisted of one box and also a little less than 5% of the students made a CES that consisted of twelve separate cause-effect relations. The most students (around 22%) made a CES that consisted of three separate cause-effect relations. It was expected that the more separate cause-effect relations in a CES, the higher the number of errors would be. In figure 12, it can be seen that this is not necessarily the case. About 5% of the students are able to make a CES that consisted of twelve cause-effect relations and they did not made as many mistakes compared to the number of mistakes made by students with a CES that consisted of six, nine or ten boxes.

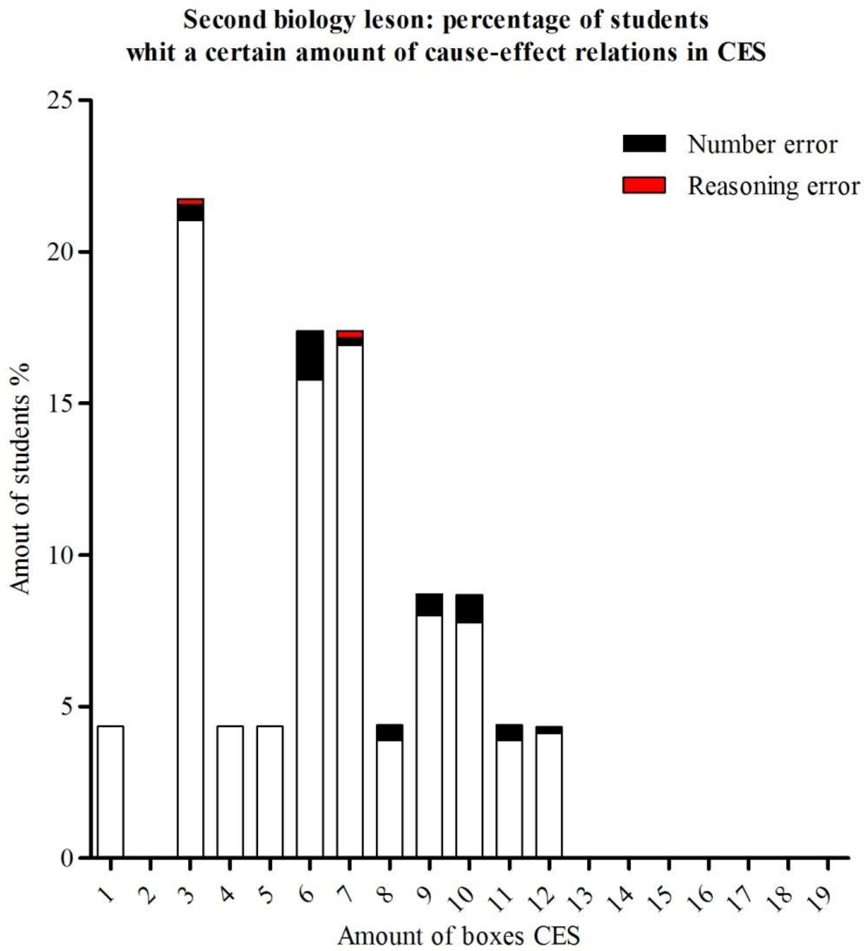

Fig 12. The number of students with a certain number of components in a CES.

Figure 13 shows the level of difficulty per cause-effect relation or per box of the CES. In annex 6, it can be seen which box number represents which cause-effect relation. The histogram shows the number of students (as a percentage of the total number of students) who used a certain cause-effect relation (referred to as box number) in their CES. The black parts of the bars of the histogram are marked as "Number error". This black part represents the number of students who used a certain cause-effect relation and did not make the difference or did not make the right difference between a little HDL (box 4) and a lot of LDL (box 7). Also students who did not mention (the right) amounts in further reasoning about LDL and HDL (box 5, 6, 8 & 9) were counted as "number error". The red parts of the bars of the histogram are marked as "Reasoning error". This red part represents the number of students that used a certain cause-effect relation in their CES and did not correctly use it in their CES. So these students made a wrong connection between separate cause-effect relations in their CES and connected boxes to each other that are not part of the same relation. From figure 13, it can be seen that box 6 and box 12 were not used by students in their CES. As in the second lesson on the subject physics, the students did not use the question mark in their CES (box 12) (see annex 6). Furthermore figure 13 shows that when box 5 and box 8 were used by students in their CES they did not mention the (right) amount of cholesterol transport. In all the CESs only two reasoning errors were found (box 15 & 16). Box 15 stands for: development of a blood clot. Some students thought that a blood clot developed as a direct result of eating a lot of food that contains fat. In reality this is not the case. Box 16 stands for: closing of the coronary artery. Students who had a reasoning error thought that closing of the coronary artery was a direct result of having LDL in your blood. In reality this is not the case. Finally it is noticeable that the boxes discussed in class (box 1, 15, 16 & 17) were not used by all students in their CES. All student CESs can be found in annex 7.

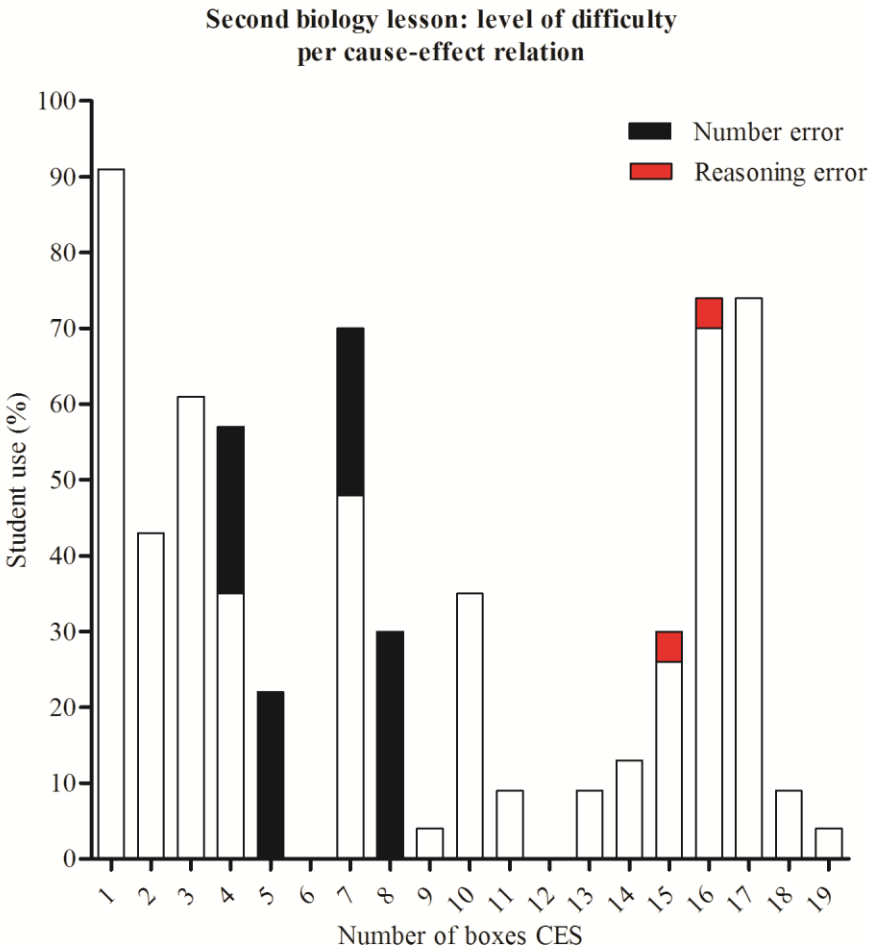

Fig 13. The number of students with a certain number of components in a CES.

Also all CESs from the last lesson about heart attack were categorised by the categories of Hennessey. All CESs can be found in annex 7. In table 8, it can be seen which percentage of students made a CES belonging to a certain category of Hennessey. As expected, no students were unable to make a CES that had the characteristics that are described in the fifth and sixth category of Hennessey. The largest proportion of the students (57%) made a CES that had characteristics that belong to the third category. 35 % of the students made a CES in which the separate cause-effect relations were connected with arrows, for example. The smallest number of students made a CES that was categorised in the first and fourth category of Hennessey.

Table 8. Categorisation of the CES which students made in the third lesson in the categories of Hennessey (K= .92)

Category of Hennessey	Description of CES	Percentage of students who made a CES in a certain category
1. Conceptions	Students use only separate boxes/cause-effect relations in the CES without connections to other boxes/cause-effect relations	4%
2. Reasoning	Students use connecting elements (arrows between boxes) in their CES	35%
3. Implications	Students are able to make a distinction between HDL and LDL in the CES and are able to reason consistently with this distinction. Students are able to apply the CES and see the practical use	57%

4. Thinking Process	Students make a CES that shows more information than the information that is given by the teacher and information source	4%
5. Status	It is not expected that CESs of students will be found in this category	0%
6. Conceptual Ecology	It is not expected that CESs of students will be found in this category.	0%

Lesson 1, 2 and 3: observations categorised by Hennessey

Table 9 shows the categorisation of student comments and observations from all the lessons. In this table, it can be seen that the number of comments and observations in the first category of Hennessey decrease as more lessons about cause-effect thinking are taught. The opposite is the case with the third and fourth category of Hennessey. This number of comments and observations increases as more lessons about cause-effect thinking are taught. As expected, the fifth category of Hennessey is not assigned to any comments or observations.

Table 9. Student comments and observations from the three lessons categorised by the categories of Hennessey (K=.86).

Category of Hennessey	Example	Percentage of student comments /observations		
		Lesson 1	Lesson 2	Lesson 3
1. Conceptions	Statements from students that prove that students can describe their own thought and that students are aware of the thinking of peer students	44%	60%	8%
2. Reasoning	Statements from students that prove that students are able to explain why he/she is thinking something	44%	0%	0%
3. Implications	Statements that prove that students can consider what errors or positive effects may result when their concepts are applied in a new situation	11%	20%	77%
4. Thinking Process	Statements from students which indicate that they will use cause-effect thinking or making a CES again.	0%	20%	15%
5. Status	Students ask critical questions about the content of cause-effect thinking. See category description.	0%	0%	0%

Results Section 2

The first research question asks to what extent biology and physics classes which explicitly teach cause-effect thinking contribute to recognising and applying this crosscutting concept in a new situation. In annex 3, it can be seen which of the survey questions relate to research question 1. From the discussion during the first lesson, it can be seen that the students who gave answers during the discussion had no difficulties in giving an example of a cause-effect relation. From the surveys, it can be calculated that after the first lesson 56% of the students are able to give a good example of a cause-effect relation (survey question 5 (sq5)). After the third lesson 100% of the students are able to give a good example of a cause-effect relation and are able to indicate the cause and effect (sq3). In order to give an example of a cause-effect relation, students must be able to apply cause-effect thinking in a new situation. Therefore answers to these questions belong to the third implication category of Hennessey (table 7). After the third lesson about cause-effect thinking, 98% of the students are able to recognise a cause-effect relation (sq2) and 24% of the students recognise a non-cause-effect relation as a cause-effect relation (sq1). When students are able to recognise a cause-effect relation, they show skills that belong to the first category of Hennessey. But when students are asked to recognise a cause-effect relation and explain why the relation is a cause-effect relation, student shows skills that belong to the second category of Hennessey. When students are asked how to explain cause-effect thinking (sq4), students are asked to show the ability to use skills that belong to the third category of Hennessey. 35% of the students explain how they made a CES and what thinking steps they made in their head. 33% of the students answer this question in terms of "action and reaction". An example of this sort of explanation: *"Je kijkt eerst naar de actie en dan naar de reactie die daarop volgt."* 12 % of the students explain cause-effect thinking in terms of their own definitions of cause and effect. Another 12 % of the students refer to something they did during class or to the context in which cause-effect thinking was taught. A very small number of the students (8%) refer to a teacher for an explanation of cause-effect thinking. The first three answers show that students are able to apply cause-effect thinking in a new situation. Therefore answers to these questions belong to the third implication category of Hennessey (table 7). Students who answer the question by referring to the lesson or to the teacher show that they are not functioning as described in the third category of Hennessey. A summary of these results can be found in table 10.

Table 10. Overview of the results from surveys that answer research sub question 1.

Research question	Learning effect/ teachers opinion related to research questions	Percentage of students after lesson 1/answer after lesson 1	Percentage of students after lesson 3/answer after lesson 3	Hennessey Category
Research sub question 1	Students are able to give an example of cause-effect relation	56%	100%	3. implications
	Students recognise cause-effect relation	-	98%	1. conceptions
	Students recognise a non-cause-effect relation as a cause-effect relation	-	24%	2. reasoning
	Students are able to explain cause-effect thinking	-	35%: explain making CES & thinking steps 33%: "action and reaction" 12%: definition cause & effect 12%: refer to lesson 8%: refer to teacher	3. implications

The second research question asks to what extent the implementation of the crosscutting concept cause-effect thinking supports biology and physics education. During the three lessons there was no discussion about this question. The only results for this question were gathered by student surveys and via interviewing teachers. After the first lesson 81% of the students would use cause-effect thinking again (sq4), after the third lesson this percentage had decreased to 32% (sq6). In contrast, 54% of the students think that making a CES helps them with learning (sq5). When students are able to pass judgment on the re-use and effectiveness of cause-effect thinking, students function as described in the fourth category of Hennessey. Not only were students questioned, teachers were also asked what they thought of cause-effect thinking and the effectiveness of it for their subject (interview question 5 (iq5)). The following response was given by the biology teacher who taught the first lesson:

"*I found the lessons about the crosscutting concept cause-effect thinking very useful. By participating in this project I got more examples from the practical about food and digestion. I also think that the lesson we made is in line with the concept-context approach, for example bacteria and food safety. By making CES, I think that students have a more complete overview of what is happening in the body in the case of food poisoning."*

The physics teacher was also enthusiastic about the lesson:

"*During the lesson I saw that students have a well-organised picture of the difference between absorption, insulation and reflection. It was a lesson in which students were activated and connected theory and practice. I think that these three factors determine why I find it a useful lesson. I also think that these three factors together led to a better understanding in students compared to a more traditional lesson in which a teacher explains theory. I personally find it exaggerated to explicitly address cause and effect and I do not see an added value in this. I find this mainly because students do not have to know this knowledge in physics. In general I think cause-effect thinking is important, but the subject physics is not very suitable for this crosscutting concept.*

The second biology teacher saw other benefits of cause-effect thinking:

"*When students have to make a CES, they have to think critically about the phenomenon about which they have to make a CES. Students can figure out by themselves how the phenomenon is established, or which cause-effect relations the phenomenon consists of by asking themselves/the teacher questions. When students get all information by being told by the teacher, students are not forced to think critically and their understanding will not be as good as when they have to figure the phenomenon out by themselves."*

A summary of all these results can be found in table 11.

Table 11 Overview of the results from surveys that answer research sub question 2.

Research question	Learning effect/ teachers opinion related to research questions	Percentage of students after lesson 1/answer after lesson 1	Percentage of students after lesson 3/answer after lesson 3	Hennessey Category
Research sub question 2	Students would use cause-effect thinking again	81%	32%	4. thinking process
	Students who think cause-effect thinking helps learning	-	54%	4. thinking process
	Teachers opinion on the effectiveness of cause-effect thinking in their subject	-	Biology teacher (lesson 1): - In agreement with concept-context approach - Students have deeper understanding of food poisoning Physics teacher (lesson 2): - Activating lesson - Deeper understanding by connecting theory and practice Biology teacher (lesson 3): - Stimulates critical thinking - Stimulates asking question about the context in which cause-effect thinking is learned - Helps students to structure a complex text - Helps teachers to gain insight in where students get stuck and adapt their help to this insight so that students get specific feedback	-

The third research question asks to what extent the crosscutting concept cause-effect thinking in the subject physics differs from in the subject biology. During the three lessons there was no discussion about this question. The only results for this question were gathered by student surveys and via interviewing teachers. After the third lesson students were asked if they saw differences between cause-effect situations in biology and physics. 56% of the students saw differences, of which 68% of the students only saw differences in the context in which cause-effect thinking was taught. Teachers were also asked the same question (iq6). Answers from the teachers to this question all consist of the same elements. The first element is that in the subject physics cause-effect relations are captured in formulas. Students don’t need to understand or to explain the formulas. In contrast to physics, in the subject of biology cause-effect relations are important and students have to know about and explain a lot of cause-effect relations. Cause-effect relations are rarely translated to formulas in the subject biology. Because cause-effect relations are important in the subject of biology, a lot of useful examples can be found. This is not the case in physics. Another big difference between the subjects biology and physics consists of the number of different organisation levels. In physics, a causal relation mostly consists of different cause-effect relations that are organised in the same organisation level. This is not the case in the case of biology. One causal relation mostly consists of different cause-effect relations from different organisation levels. Sometimes, this makes causal relations in biology very difficult for students.

CONCLUSION AND DISCUSSION

The central question of this study is: what are the learning effects of explicitly teaching the crosscutting concept cause-effect thinking in lower secondary science education? In order to answer the central question, three sub questions are formulated. The first sub question asks how cause-effect thinking can be taught to students so that they are able to recognise and apply this crosscutting concept in a new situation. This study shows that elements of cause-effect thinking can be learned by students via a cause-effect scheme. Observations from lessons show that students find it a very logical way of thinking that is taught in a logical way. Results show that after the third lesson about cause effect thinking all students are able to give an example of a cause-effect relation and all students are also able to explain cause-effect thinking to another student. 98% of the students are able to recognise a cause-effect relation, but 24% of the students recognise a non-cause-effect relation as a cause effect relation. This result needs an annotation regarding the example that was used to obtain this result. The question and example that were used were the following: Is the example mentioned below an example of cause-effect thinking? And give an argument. Example: My dog is due in two weeks. According to the vet she is having three puppies (annex 3, survey questions after the third lesson, first survey question). According to the arguments, some students did not interpret the example in the same way as the researchers. The researchers labelled this example as not a cause-effect relation but as something that will happen over time. 24% of the students labelled this example as a cause-effect relation in which "my dog is pregnant" is the cause, and "puppies" are the effect. The argument students gave is that puppies do not arise spontaneously. When two dogs have sexual intercourse, they have puppies.

Analyses of the CESs that students made in the second and third lessons show that students demonstrated a capability of making gradually more complex CESs. In the second lesson students were able to make a CES that consisted of three to ten cause-effect components (see figure 8). During the last lesson, some students were able to make a CES that consisted of twelve components from a more complex text (figure 12). It was expected that the more separate cause-effect relations in a CES, the higher the number of errors would be. Figures 8 and 12 show that this is not necessarily the case. A possible explanation is that students who make a CES that consists of a lot of components have better understanding of cause-effect thinking, are more capable of making a CES and have a deeper understanding of the context (physics lesson: reflection, absorption and insulation. Biology lesson: heart attack) and therefore make fewer mistakes in their CES.

Observations from all lessons show progress in cause-effect thinking. Table 9 show the categorisation of student comments and observations from all the lessons. In this table, it can be seen that the number of comments and observations in the first category of Hennessey decrease as more lessons about cause-effect thinking are taught (from 44% in the first lesson to 8% in the last lesson). The opposite is the case with the third and fourth category of Hennessey. This number of comments and observations increases as more lessons about cause-effect thinking are taught. In the first lesson 11 % of all observations and comments from students were categorised in the third category and in the last lesson this percentage increased to 77%. For the fourth category this percentage increased from 0% in the first lesson to 15 % in the last lesson. These results underpin the progress of students in their capability of cause-effect thinking.

The CESs from the third lesson were analysed more deeply by categorising the CESs in the different categories of Hennessey. The results of this analysis can be found in table 8. When students are able to recognise and apply cause-effect thinking, the crosscutting concept will be useful for students. The third category of Hennessey describes student behaviour and components of a CES that students made who are able to apply cause-effect thinking. All categories of Hennessey above the third category show that students are able to apply cause-effect thinking and all categories under the third level of Hennessey show that students are not able to apply cause-effect thinking. After the third lesson 57% of the students were able to make a CES that showed that students are able to apply cause-effect thinking (table 8, implications category of Hennessey). 4% of the students made a CES that was categorised in the fourth category of Hennessey. This means that 61% of the students were able to apply cause-effect thinking after three lessons about cause-effect thinking and how to make a CES. These results underpin the conclusion that cause-effect thinking can be taught to students by making a CES.

The conclusion and results mentioned above show that by teaching students cause-effect thinking via CES, students improve their ability in cause-effect thinking and making a CES. This study cannot conclude with absolute certainty that the lessons about cause-effect thinking led to the previously discussed progress, because this study is a qualitative study without a control group who were not taught about cause-effect thinking and making a CES. However, observations show that students had a lot of questions during the first and second lessons about what was expected from them (*"What should I do?"*), what the best method of working was (*"What is the beginning of the CES? And what is the end? How many boxes does this CES contains? Is this correct?"*) and what crosscutting concept or way of thinking they should use (*What is the cause? And what is the effect?"*). During the last lesson about cause-effect thinking, students did not ask these questions any more. After the explanation of the assignment from the teachers, students knew what was expected of them, what the best method of working was and what crosscutting concept they should use. The absence of student questions after the third lesson suggests that students learned a certain way of thinking (cause-effect thinking) and working (making a CES) that they did not know or were not capable of before the first lesson.

Answers to the first sub question are based on different research tools. The progress made in making a CES is based on analyses of CESs from students from the first and last lesson and also on observations from all the lessons. The progress made by students in cause-effect thinking is based on student statements from lesson observations, analyses of CESs that students made during the third lesson and answers from students to survey questions. Because different research tools have been used that focus on different aspects of the educational process, answers to the first sub question will be considered a reliable conclusion.

The second sub question asks how far the implementation of the crosscutting concept cause-effect thinking supports biology and physics education. To answer this sub question, results from table 11 can be used. After the first lesson 81% of the students would use cause-effect thinking again. This percentage dropped after the third lesson to 32%, but 52% of the students think that cause-effect thinking helps their learning. An explanation for these numbers can be found in the motivation of students. In all lessons about cause-effect thinking students had to make a CES and all lessons took place in a short period of time. These two circumstances caused the motivation of students for this activity to drop during the lessons. This could explain the negative answers of many students to the question of whether they would use cause-effect thinking again. It could also be that students reacted positively to the first lesson, because the first lesson was different to the lessons they were normally taught. A short instruction followed by activating student assignments in which they should work together with peer students are elements of the lesson which make this lesson different. Another possible explanation of the drop in motivation could have to do with the amount of scaffolding during the different lessons. In the first lesson, students had to fill in a fully structured scheme. During the third lesson, students did not have a scheme that helped them to make a CES, they had to make a CES by themselves. Because the lessons were scaffolded, students had to carry out more aspects of making a CES by themselves. It could be that students did not appreciate the gradual increase in aspects of cause-effect thinking and complexity of the context in which cause-effect thinking was taught.. A possible last explanation can be related to the preference of students for a certain way of learning. Some students do not like new ways of learning, because they are familiar with their own way of learning and they know that their familiar way of learning is successful. Learning a new way of learning asks students to invest extra time in this way of learning. When students do not see the added value of a new way of learning and their familiar way of learning is successful, they are not willing to invest time in the new way. In this case, learning a new way of learning is very difficult. Altogether, it can be concluded that students think that cause-effect thinking helps their learning, but the lessons about cause-effect thinking should be spread over a longer period of time and should vary in student assignments.

The teachers were also asked about the effectiveness of cause-effect thinking in their subject. The biology teacher of the first lesson finds that the lesson was in agreement with the 'Context-concept' educational learning approach. She also thinks that students have a deeper understanding of food poisoning, compared to students who were not taught about cause-effect thinking. The physics teacher from the second lesson thinks that the lesson is an activating lesson in which theory and practice were connected, which resulted in a deeper understanding. She thinks it exaggerated to explicitly address cause and effect, because students do not have to have this knowledge in physics. On the other hand she thinks that cause-effect thinking is important, but the subject physics is not very suitable for this crosscutting concept. The second biology teacher (= the researcher) who taught the third lesson thinks that cause-effect thinking stimulates students to think critically and ask questions. Altogether, teachers think that cause-effect thinking supports biology education. After making the lessons about cause-effect thinking, the researcher thinks that cause-effect thinking and making a CES can also help students in structuring a complex text. By making a CES of a difficult and complex text, teachers can see very precisely where in the text students get stuck and adapt their support to that point which students find hard to understand. By making a CES students can come up with critical questions about the context because a CES forces students to figure out the context in which cause-effect thinking is thought out to the last detail. As this may lead to new unanswered questions, this may become confusing for certain students who prefer learning certain knowledge.

Answers to the second sub question can also be considered to be reliable because different research tools have been used that focus on different aspects of the educational process. Students were asked to fill in survey questions, teachers were interviewed and observations were made by the researcher, so different point of views (teacher, student and researcher) and different methods (observation, survey questions and interview) were used. Therefore answers to the second sub question can be considered a reliable conclusion.

The third and final research sub question asks if the crosscutting concept cause-effect thinking in the subject physics differs from cause-effect thinking in the subject biology. If so, what differences do teachers and students see? By asking students and teachers this via surveys and interviews, data to answer this question were gathered. After the third lesson 56% of the students saw differences in cause-effect thinking between the subjects biology and physics. 68% of these students saw differences in the context in which cause-effect thinking was taught and not in the crosscutting concept cause-effect thinking itself. It could be that because of the differences in activities between the biology and physics lessons it was difficult for students to focus on the differences in cause-effect thinking. The teachers were also asked if they saw difference in cause-effect thinking in the subjects biology and physics. Both teachers' answers to this question consist of the same elements. The first element is that in the subject physics cause-effect relations are captured in formulas. Students don't need to understand or to explain the formulas. In contrast to physics, in the subject of biology cause-effect relations are important and students have to know and explain a lot of cause-effect relations. Cause-effect relations are rarely translated into formulas in the subject biology. Because cause-effect relations are important in the subject of biology, a lot of useful examples can be found. This is not the case in physics. Another big difference between the subjects biology and physics consists of the number of different organisational levels. In physics, a causal relation mostly consists of one or a few cause-effect relations that are organised in the same organisational level. This is not the case in the case of biology. One causal relation mostly contains different cause-effect relations in different organisational levels. Sometimes, this makes causal relations in biology very difficult for students. Altogether, it can be concluded that most students do not see differences in the way of thinking in the crosscutting concept cause-effect thinking, but they see differences in the context in which cause-effect thinking is taught. Teachers see differences between the subjects in cause-effect thinking with regard to three points:

- The most cause-effect relations in the subject physics are captured in formulas of which students in lower secondary science education do not have to understand the underlying mechanisms
- Most cause-effect relations in the subject biology are complex because they consist of different cause-effect relations that are organised in different organisational levels
- In biology, many examples and practical applications can be found that are within reach of lower secondary science students

These differences also indicate that the type of cause-effect thinking studied in this research could be more helpful in learning biology than in learning physics.

Answers to the third sub question can also be considered a reliable conclusion, because students were asked to fill in survey questions and teachers were interviewed. In this case there were no results gathered by making observations, because this third sub question only relates to the opinion of teachers and students.

Now all the sub questions have been answered, the central question of this study can be answered. This study asks what the learning effects are of explicitly teaching the crosscutting concept cause-effect thinking in lower secondary science education. As a model for cause-effect thinking, the ability to distinguish chains and ramifications of cause-effect relations was researched in lower secondary science students at havo-level. The explicit teaching involved the gradually more independent creating of cause-effect schemes from a given context. In this study most students learned quickly to apply cause-effect schemes, and showed cause-effect reasoning. This reasoning can be indicated as conscious but not idiomatic (van Oers). Half of the students indicated that cause-effect thinking helped them but motivation for using the cause-effect scheme dropped during the lessons. In contrast to teachers, students do not see differences in cause-effect thinking between the subjects biology and physics, because students do not have a meta-level overview of the subjects biology and physics.

Didactical suggestions

Based on the conclusions, results and lesson observations some suggestions are given in order to improve the implementation of cause-effect thinking in the classroom.

In all lessons, the question mark in the CES was not understood by students. In the first lesson the students placed the question mark in a place that was left over. In the second and third lesson, the question mark was not used by students (see figure 9 box 10 and figure 13 box 12). Purpose of the question mark was that students were stimulated to think critically about whether a cause-effect relation was really explained in the text. So to stimulate critical thinking in students more didactical methods than placing and introducing a question mark should be used. A follow-up study could investigate how students can be stimulated to think more critically during cause-effect thinking. One way could be that teachers pay more attention to the question mark during the first lesson and explain to students what it means, when they can use it and what question students could ask themselves when a question mark is placed in a CES. It could also be that the question mark is not the most effective way to stimulate students to think critically, but another didactical method is more suitable to stimulate critical thinking.

Another didactical suggestion concerns student motivation. In this study, students had to carry out the same type of assignment more than once in a short period of time. This led to a decrease in motivation for this activity, so lessons about cause-effect thinking should be spread over a longer period of time and should vary student assignments to keep students more motivated. On the other hand, some continuity in the assignments is needed for students to understand what the cause-effect strategy entails, so different assignments should contain common and recognisable elements of cause-effect thinking.

To motivate students it is also important to show students what their personal benefit is from cause-effect thinking and what practical applications cause-effect thinking has. To let students see what kind of practical applications cause-effect thinking has, it is very important to choose the right context in which cause-effect thinking is taught. This advice is important considering one of the discussion points about the difficulty of convincing students to learn another way of learning than the one they are familiar with. Students have to be convinced to give up their own familiar way of learning and be prepared to invest time in a new way of learning. Cause-effect thinking should only be taught in a context in which this crosscutting concept can be expected to help students with their learning and understanding. Examples of complex causal relations that occur over different organisational levels are more suitable than examples in which causal relations are hard to find, as was the case in the physics lesson.

The last didactical suggestion concerns ways of scaffolding and differentiation in class. In this study only three steps of scaffolding took place and all students received the same amount of support. In class, more smaller steps of scaffolding should take place and the support to students should be differentiated to suit the specific help students need. Differentiation can easily take place, because the scheme shows teachers where students get stuck in the process and thereby teachers can adapt their help to the specific needs of a student. Suggestions to alter the scaffolding during the second and third lessons:

- Teacher and students fill in the first and last steps of the CES together
- Teacher and students fill in the first or last steps of the CES together
- Teacher explains explicitly a way of thinking when students get stuck in making a CES, by asking help questions

Follow-up studies could focus on the support that students get during cause-effect thinking from their teachers. In particular, the kind of questions teachers should ask students to stimulate and support cause-effect thinking would be interesting to investigate. The effects of variation in student assignments could also be investigated. Does diversifying student assignments have an effect on the ability of students to use cause-effect thinking and on their motivation? Another study could focus on the same research question but with a different method, by adding a control group and increasing the number of students and teachers that participate in the study.

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ANNEX 1 HYPOTHETICAL LEARNING TRAJECTORIES

Hypothetical learning trajectory lesson 1 food poisoning

Lesson element	Teacher activity	Student activity	Hypothesized learning result	Learning cause-effect thinking
Introduction research	Introducing observer Explaining recording lesson, observations and studying students assignments	Listening	Students understand why they are filmed, observed and why their assignments are studied	-
Introduction subject: food poisoning	Introduction subject by asking students experience with food poisoning Instruct students to make assessment 1 and 2 Discuss assessment 1 and 2	Some students share their experience with food poisoning Students make assessment 1 and 2 Students share their answers to assessment 1 and 2	Activating prior knowledge on food poisoning and cause effect relations Students have a clear and workable understanding of a cause effect relation. Students understand the difference between a cause effect relation and a relation that will happen over time	Assessment 1: Students are asked: where do you think of by the words cause and effect? Assessment 2:Students determine which of the two following examples is an example of cause effect thinking and why this is an example of cause effect thinking. Example 1: As the afternoon progresses, the sun goes down. Example 2: By pressing on the on-button of the TV, the TV turns on
Description food poisoning	Starting assessment 3 by asking: where do you suffer from if you have food poisoning?	Listening Thinking about the symptoms of food poisoning	Students know what the symptoms are of food poisoning	Assessment 3 is the starting point for filling in the CES in assessment 5. If students find the right symptoms, the effect of the CES is known.

	If necessary: explain the term symptom Explain short assessment 4 and 5. Mark the empty boxes and question mark		Students understand the term symptom Students know what is expected of them in assessment 4 and 5	
Working on assignments	Support students if necessary with asking the right questions (how- and what questions) Pick out one pair of students how will put op there CES in front of the class	Students define the cause effect relations of the CES Students put the right cause effect relations to each other in the CES	Students realize that they first need to define the different cause effect relations of the CES Students can put together cause effect relations that belong together	In assessment 4 students determine all the different components/boxes of the CES. These components/boxes are the different cause effect relations that form together the CES In assessment 5 students fill in an fully structured CES in which they fill in the given CES components/boxes. Students have the opportunity to add their own empty boxes and alter the structure of the CES if they want
Discussing assignments in class	In the discussion assignment 5 should be emphasized. The CES on the blackboard is the starting point of the discussion. Ask other students if there are similarities and differences to their CES. If there are no reactions, ask students if these cause effect relations are right. Ask students what the question mark means and why students put in the way they did.	Students compare to, discuss with and think critically about their CES with the CES on the blackboard Students participate in the discussion Students think of ways to prevent food poisoning with the CES in mind	Students experience that they have to think critically (by asking themselves questions) in order to make a realistic CES Students recognize the 5 types of cause effect relations Students see applications of a CES and why it can be useful to them	By discussing the CES on the blackboard students develop an toolkit which they can use the next time they make a CES. This toolkit consist of step-by-step plan about how to make an CES, a range of questions students can ask themselves, the knowledge about which possible building blocks a CES can been build up and how students can use these building blocks

	Ask students what they can do to prevent food poisoning Make students clear what different steps they made to come up with the CES Ask students if there are any questions of other experiences they want to share	Listen and react	Students realize that there are different method to make a CES, but that the questions you ask yourself are always the same	
Complete survey	Give the link for the survey to students	Students fill in the survey	-	

Hypothetical learning trajectory lesson 2 reflection, absorption and insulation

Lesson element	Teacher activity	Student activity	Hypothesized learning result	Learning cause-effect thinking
Introduction lesson	Introducing today's programme Showing time table	Listen	Students know what is expected of them this lesson and in the follow up assignment (writing an advice)	Students prepare themselves by bringing up their toolkit
Discuss homework assessment in class	Ask if students have any questions about reflection, absorption or insulation Shortly discuss the right answers from the homework assessment	Ask questions if necessary Check and if necessary correct answers from the homework assessment	Students understand the processes reflection, absorption and insulation Students know the first cause and the last effect of the CES	In the homework assessment students determine main cause and effect (end and beginning of the CES). By discussing the homework, students get feedback on their performance and way of thinking
Experiment and making CES	Divide the class in groups of 6 students. Divide the groups of 6 in a CES group (3 students) and a experiment group (3 students) Experiment group start with the practicum. When the experiment group is finished, they swop roles with the SEC group In the experiment group 1 student will do the reflection experiment, 1 student will do the absorption experiment and 1 student will do	Make the CES in a threesome on the worksheet. If needed they can use the help questions Students put the right cause effect relations to each other in the CES Do the experiment and fill in the different characteristics of the different materials in the experiment. Fill in the results on the worksheet	Students are able to fill in a more open CES Students experience which materials have the biggest effect on the volume Student experience and know the characteristics of the materials that have the biggest negative impact on the volume	Making CES: students fill in a less structured CES. In the given CES only the first cause is given and from the homework discussion students know the last effect. Experiments: students experiment in which way the isolation-, absorption- and reflection materials can be used to get less noise pollution. Students how first make the CES and afterwards do the experiment are able to: test their CES, see where in the CES they are able to interfere with isolation- absorption- and reflection materials to minimize noise pollution and see the usefulness and application of a CES.

	the insulation experiment. This distribution of tasks is the same for the CES group after swopping. Together the 3 students of the CES group will make the CES Show the students how the worksheets should be filled in and where students of the CES group can find help if they need to Help students by asking questions. For the experiment for example: how does the material look like? By using which material you had the lowest sound level? For the CES there are on the worksheet questions which students can ask themselves			Students who first do the experiment and afterwards make the CES are able to experience experimentally by trial and error which isolation- absorption- and reflection materials minimize noise pollution the best. Based on these experience students can make a CES. Students also can see the usefulness and application of a CES. In this lesson phase students fine tune their toolkit by doing the experiment, making the CES and discussion their activities with peer-students and the teacher.
Exchange practicum results	Start with a short repetition of what is expected from students by writing the advice Show students how to fill in the exchange working sheet	Students exchange their practicum results	It is clear for students what is expected of them by writing the advice Students have all the data to write an advice	-

(Writing advice)	(Help students if they have any questions about the advice or practicum)	(Students can start writing the advice)	(Students can apply the CES and results together in writing an advice)	Students need to combine the information from the CES and de results from the experience to write an advice on how to minimize the sound pollution in their residence. By writing about cause effect thinking students need to communicate the information. In this way teachers can check for two criteria from Van Oers and can say something about cause effect thinking as metacognitive strategy
Complete survey	Give the link for the survey to students	Students fill in the survey	-	-

Hypothetical learning trajectory lesson 3 heart attack

Lesson element	Teacher activity	Student activity	Hypothesized learning result	Learning cause-effect thinking
Introduction lesson	Introducing programme today Showing time table	Listen	Students know what is expected of them this lesson	Students prepare themselves by bringing up their toolkit and prior experience with making a CES
Videos	Show the two videos that make the content of source 1 visual	Listen and watch the videos	Students see the process of which they have to make a CES	-
Making CES	Explain today´s assessment Central question: why do you have an increased health risk if you eat too much food that contains saturated fat Determine together with the students the first cause and the end effect Explain that one post-it represents one box of the CES Put students to work in pairs with the CES	Listen Read source 1 Determine first cause and end effect Make a CES Participate in class discussion	Students know what is expected of them Students have a starting point for making the CES with the first cause and the end effect Students have developed their own way of making a CES Students apply their own method on making the CES	Students don’t get a structured CES, they only get post-its, a source about how food that contains a lot of saturated fat can lead to a heart attack and together with peer students and the teacher the first cause and one of the last effects is determined Students make in pairs a CES scheme that answers the central question. The previous experience and the toolkit they have build in the previous lessons will help them making the CES. In this CES students have to found out how eating food that contains a lot of saturated fat will lead to an increased risk of heart attack

	If necessary stop working in pairs and discuss in class: - common mistakes - frequently asked questions - difficult parts (probably between “fat absorption in blood” and “too high levels of LDL”)			
Class discussion	Let one pair of students put their CES on the blackboard Ask other students if there are similarities and differences to their CES. If there are no reactions, ask students if these cause effect relations are right. Ask students what can be done to prevent a heart attack. If they don’t come up with solutions, refer to the CES. In which cause effect relations they can intervene?	Students compare to, discuss with and think critically about their CES with the CES on the blackboard Participate in class discussion Listen en react Use the CES to think of ways to prevent a heart attack	Students realize that there are different method to make a CES, but that the questions you ask yourself are always the same Students see applications of a CES and why it can be useful to them	By discussing the CES on the blackboard students can fine tune their toolkit and check their CES. By asking students what can be done to prevent a heart attack, students have to read their own CES, pick out the right information to answer this question and formulated this answer in understandable language. So students apply their CES to solve a question
Complete survey	Give the link for the survey to students	Students fill in the survey	-	-

ANNEX 2 LESSON MATERIALS

Lesson 1

Opdrachten voedselvergiftiging en oorzaak-gevolg denken

1. Waarbij denk je aan als je aan oorzaak en gevolg denkt?

2. Hieronder staan twee voorbeelden. Één hiervan is een voorbeeld van een oorzaak-gevolg denken. Geef aan welke volgens jou een voorbeeld is van oorzaak-gevolg denken en waarom. Geef ook aan waarom het andere voorbeeld geen goed voorbeeld is van oorzaak-gevolg denken.

   Voorbeeld 1:
   Hoe later na twaalf uur 's middags, hoe lager de zon aan de hemel staat.

   Voorbeeld 2:
   Door op de aanknop van tv te drukken, gaat de tv aan.

Zoals in afbeelding 14 op blz. 50 is te lezen hebben de spelers van het voetbalelftal van Atletico Madrid last van voedselvergiftiging. We gaan met deze opdrachten bekijken hoe het komt dat ze voedselvergiftiging hebben opgelopen.

3. Waar hebben de spelers last van? Anders gezegd, wat zijn de symptomen van voedselvergiftiging?

Bekijk bron 1 het volgende filmpje: https://www.youtube.com/watch?v=GTz8cYqP16k

Bron 1

Wat gebeurt er in mijn lichaam bij een voedselvergiftiging?

Nadat je voedsel hebt gegeten waarop bacteriën of schimmels zitten kunnen er twee dingen gebeuren. In dit geval kijken we naar de belangrijkste oorzaak van voedselvergiftiging. Hierbij produceren bacteriën of schimmels toxines. Voordat deze toxines worden gemaakt, vermenigvuldigen bacteriën/schimmels zich in het voedsel. Dit vermeerderen gebeurt alleen onder bepaalde omstandigheden: je lichaam moet de juiste temperatuur hebben, er moet voldoende vocht aanwezig zijn en er moeten voedingsstoffen aanwezig zijn. Wanneer je veel bacteriën of schimmels in je lichaam hebt, kunnen er ook veel toxines worden gemaakt. Deze toxines worden samen met het voedsel en de bacteriën of schimmels naar de maag en darmen verplaatst om het voedsel te verteren. In de darmen aangekomen, kunnen de geproduceerde toxines de werking van het maag- darmkanaal verstoren. Door deze verstoring kun je last krijgen van de symptomen die horen bij voedselvergiftiging. Dit proces gebeurt ook in je lichaam wanneer je voedsel hebt gegeten dat verontreinigd is met een chemische stof.

4. Maak een lijstje van alle zaken die in het filmpje en in bron 1 voorkomen die invloed hebben op voedselvergiftiging.

Om meer inzicht te krijgen in hoe een voedselvergiftiging ontstaat, helpt het om een oorzaak-gevolg schema te maken. Hieronder staan aanwijzingen hoe je dat kunt doen.

BOX 1. Het maken van een oorzaak-gevolg schema

Er zijn vier typen oorzaak-gevolg relaties:

1. Één oorzaak leidt tot één gevolg

Oorzaak → gevolg

2. Meer oorzaken samen leiden tot één gevolg

OORZAAK 1 ↘

GEVOLG

OORZAAK 2 ↗

3. Één oorzaak heeft meerdere gevolgen

↗ GEVOLG 1

OORZAAK

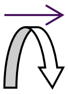
↘ GEVOLG 2

4. Bedenk ook dat een gevolg zelf ook weer oorzaak kan zijn, zodat je een keten krijgt van oorzaak en gevolg.

OORZAAK 1 → GEVOLG = OORZAAK 2 → GEVOLG 2

Naast deze drie typen oorzaak-gevolg relaties vinden sommige relaties alleen plaats onder bepaalde omstandigheden. Je geeft dit dan als volgt weer:

OORZAAK 1 → GEVOLG = OORZAAK 2 → GEVOLG 2



Omschrijving omstandigheden

5. Maak nu een compleet oorzaak-gevolg schema van voedselvergiftiging. Het schema dat op je werkblad staat moet verder ingevuld worden met termen die op je knipblad staan. Knip de termen uit en plak ze op de juiste positie in het oorzaak-gevolg schema op je werkblad.
   Zoals je kunt zien op het knipblad zijn er ook lege blokken. Deze mag je zelf invullen als je belangrijke onderdelen van het oorzaak-gevolg schema mist. Daarnaast zie je ook een ? staan. Dit is een soort joker. De joker kun je inzetten als je niet precies weet wat er gebeurt.
   Als je het niet eens bent met het voorgedrukte schema mag je ook een leeg A4-tje ophalen en helemaal zelf een schema maken. Ook mag je in het voorgedrukte schema pijlen extra erbij zetten of veranderen als je dat wilt.

6. Geef in het oorzaak-gevolg schema van vraag 5 de gevolgen een oranje kleur en de oorzaken een blauwe kleur. Let op: zoals in box 1 te lezen is kun je ook hebben dat een gevolg een oorzaak wordt (optie 3 in box 1). Geef deze vakjes twee kleuren

7. Omcirkel in het oorzaak-gevolg schema de vier typen oorzaak gevolg relaties en schrijf erbij welke relatie je ziet. Het kan zijn dat niet alle relaties in het schema te zien zijn. Je hoeft van elke relatie maar één voorbeeld te omcirkelen.

8. Probeer nu zelf een voorbeeld te bedenken bij de vier verschillende typen oorzaak-gevolg relaties.

9. Wat zou je kunnen doen om voedselvergiftiging tegen te gaan? Je kunt hier basisstof 10 op bladzijde 75 t/m 77 bij gebruiken. Geef minimaal 3 mogelijkheden om voedselvergiftiging tegen te gaan.

10. Geef de oplossingen die je bedacht hebt een nummer. Bekijk nu het schema dat je gemaakt hebt bij opdracht 3. Bedenk waar in het oorzaak-gevolg schema jouw oplossing op aangrijpt. Zet op die plek het juiste nummer van de oplossing.

Antwoordblad opdrachten voedselvergiftiging

Naam: ____

Naam partner: ____

1. ____

____

____

2. Voorbeeld 1 is wel/niet een voorbeeld van oorzaak-gevolg denken, omdat _______________

____

____

____

Voorbeeld 2 is wel/niet een voorbeeld van oorzaak-gevolg denken, omdat _______________

____

____

____

3. ____

____

____

4. - ____

- ____

- ____

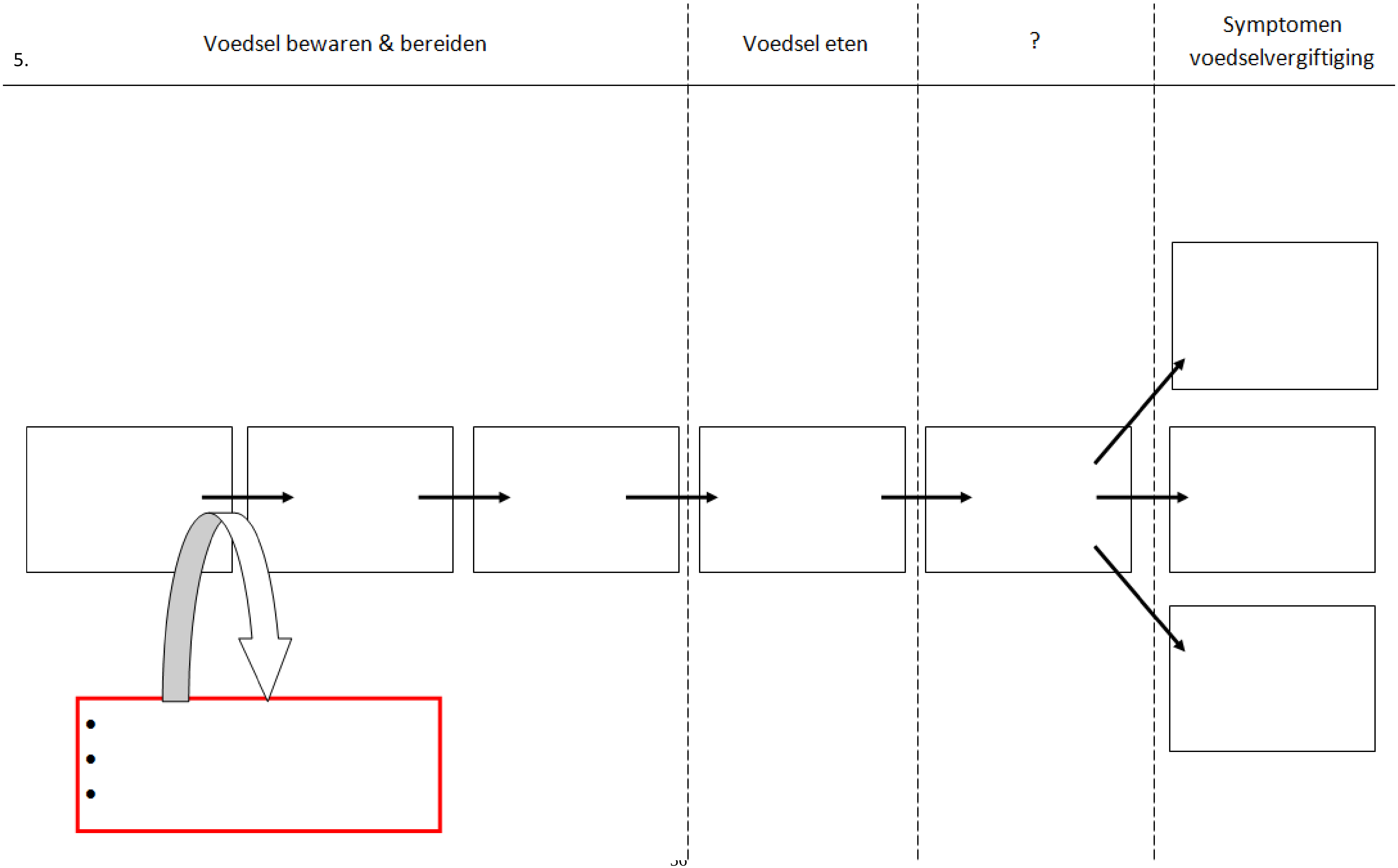
- ____

- ____

- ____

- ____

5.


Voedsel bewaren & bereiden
Voedsel eten
?
Symptomen voedselvergiftiging

8. Voorbeeld type 1:

____

____

Voorbeeld type 2:

____

____

Voorbeeld type 3:

____

____

Voorbeeld type 4:

____

____

10. ____

____

____

____

____

Knipblad voedselvergiftiging

Bacterie of schimmel op voedsel	Verplaatsing toxine naar maag-darmkanaal
?	Misselijkheid
Bacterie of schimmel in voedsel produceert toxine	
Duizeligheid	
Bacteriën of schimmels vermenigvuldigen zich in voedsel	Diarree

Knipblad voedselvergiftiging

Bacterie of schimmel op voedsel	Verplaatsing toxine naar maag-darmkanaal
?	Misselijkheid
Bacterie of schimmel in voedsel produceert toxine	
Duizeligheid	
Bacteriën of schimmels vermenigvuldigen zich in voedsel	Diarree

Lesson 2

Huiswerkopdracht

Bekijk dit filmpje over geluidsoverlast: http://w.rtvoost.nl/archief/default.aspx?nid=90359&o=1

Stel je bent inwoner van Willemsoord en je gaat de gemeente advies geven over oplossingen van de geluidsoverlast. Wat zou je zelf als inwoner kunnen doen om geluidsoverlast zo veel mogelijk te beperken? En wat kan de gemeente hiertegen doen? Op deze vragen ga je tijdens de les antwoorden zoeken door een aantal proeven te doen. Op basis van uitkomsten van deze proeven ga je de gemeente een advies geven over hoe ze het best de geluidsoverlast kunnen oplossen.

Voordat je een advies kunt geven aan de gemeente moet je wat meer weten over geluidsisolatie, geluidsabsorptie en de terugkaatsing van geluid.

Maak de vragen 1 t/m 3 met behulp van bron 1:

Bron 1

Geluid terugkaatsing

Dit gebeurt wanneer geluidstrillingen tegen bijvoorbeeld een geluidswal, geluidsscherm of gebouw komen. Wanneer ze het materiaal raken, worden de trillingen terug gekaatst naar waar het geluid vandaan kwam. De richting van het geluid is hierdoor veranderd. Vaak wordt deze methode gebruikt om het geluid (en dus de geluidstrillingen) van een bepaalde plaats weg te houden.

Geluidsisolatie

Dit zie je veel in studio's waar muziek wordt gemaakt. Hier zie je vaak dat tussen de muren geluidisolerend materiaal zoals op de afbeelding hiernaast wordt gedaan. Deze muren zorgen ervoor dat wanneer trillingen dit materiaal raken de trilling van vorm veranderd. Doordat de geluidstrillingen van vorm veranderen, wordt de amplitude van de trilling kleiner. Geluidstrillingen met een kleinere amplitude hebben een lage geluidssterkte.

Geluidsabsorptie

Door gordijnen, tapijt en behang kun je in je eigen huis veel geluid absorberen. Als je wel eens in een huis bent geweest dat net opgeleverd is door de aannemer, klinkt alles veel holler en harder dan wanneer het huis helemaal is ingericht met meubels, vloer, gordijnen en behang. Dit komt omdat bijvoorbeeld gordijnen geluid absorberen. Wanneer geluidstrillingen een gordijn raken gaan ze door het materiaal heen. Er gebeuren dan twee dingen. Ten eerste zullen de geluidstrillingen de stof van het gordijn een beetje van vorm veranderen. Dit kost de geluidstrillingen energie, waardoor ze een kleinere amplitude krijgen. Daarnaast gebeurt er ook iets met de geluidstrillingen waardoor er warmte ontstaat. Ook dit proces kost energie, waardoor de geluidstrillingen een kleinere amplitude krijgen. Geluidstrillingen met een kleinere amplitude hebben een lage geluidssterkte.

Vragen:

1. Benoem de oorzaak en het gevolg het stukje over geluid terugkaatsing.

____

____

2. Benoem de oorzaak en het gevolg in het stukje over geluidsisolatie.

____

____

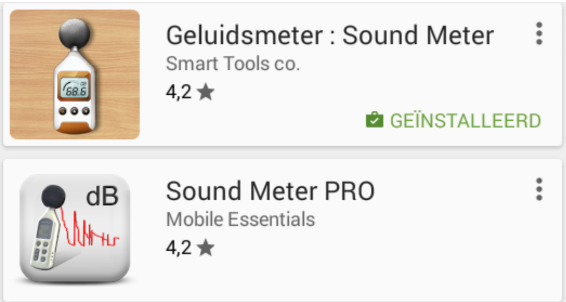
3. Benoem de oorzaak en het gevolg in het stukje over geluidabsorptie

____

____

Opdrachten

Om goed voorbereid te zijn op de proeven die tijdens de les gaat uitvoeren, moet je onderstaande twee opdrachten uitvoeren:



Opdracht 1: downloaden decibelmeter

Download via de appstore of via google play een decibelmeter. Download of de "Geluidsmeter: Sound Meter" of "Sound Meter Pro".

Opdracht 2: Geluidsfragment

Zorg ervoor dat je tijdens de proeven makkelijk toegang hebt tot de volgende link: https://www.youtube.com/watch?v=GhhcpQI3iAs. Deze youtube video (10 hour TV Beep sound PAL NTSC) ga je tijdens de proeven gebruiken. Zorg dus dat je deze video bij de hand hebt!

Werkblad oorzaak-gevolg denken

Je gaat van de processen terugkaatsing, isolatie en absorptie oorzaak-gevolg schema's maken als onderbouwing voor het advies dat je aan de gemeente gaat schrijven.

Net als de vorige keer met biologie mag je een joker plaatsen in het schema als je niet precies weet hoe het proces precies plaatsvindt. Bron 1 van de huiswerkopdracht kun je als informatiebron gebruiken om de oorzaak-gevolg schema's te maken. Je wordt een beetje geholpen doordat op de volgende pagina's een begin is gemaakt met deze schema's. Daarnaast kunnen onderstaande hulpvragen je helpen.

Hulpvragen

1. Wat is de oorzaak? En wat is het gevolg?
2. Wat gebeurt er met geluidstrillingen wanneer ze in geluidssterkte afnemen?
3. Welke tussenstappen zijn er tussen de oorzaak en het gevolg?
4. Wat is de juiste volgorde van de tussenstappen?

Terugkaatsing	Doel: minder geluidsoverlast

Geluidstrillingen van geluidsoverlast raken terugkaatsingmateriaal

Soort isolatiemateriaal	Doel: minder geluidsoverlast

Geluidstrillingen van geluidsoverlast raken isolatiemateriaal

Soort absorptiemateriaal

Doel: minder geluidsoverlast

Geluidstrillingen van geluidsoverlast gaan door absorptie materiaal

Opdracht advies schrijven

Je gaat in tweetallen een brief aan de gemeente van Willemsoord schrijven. Deze brief richt je aan de gemeente Steenwijkerland, Postbus 162, 8330 AD in Steenwijk.

Uit de brief aan de gemeente moet het duidelijk zijn wat jullie advies of adviezen zijn en wat daarvoor je onderbouwing is. Voor deze onderbouwing kun je de resultaten van de experimenten gebruiken en de oorzaak-gevolg schema's over terugkaatsing, isolatie en absorptie.

Kijk goed naar onderstaande eisen, want de brief die je schrijft is voor een cijfer. Je levert het verslag volgende week donderdag 12 november in via it's learning.

Je brief moet aan de volgende eisen voldoen:

- Adresgegevens, datum en een passende aanhef & slotgroet
- Logische briefindeling en opbouw van je advies (per alinea één advies met onderbouwing, duidelijke inleiding, middenstuk en slot)
- Bij elk advies moet een passende onderbouwing van je advies.
- Onderbouwing moet bestaan uit:
    - Specifieke verwijzing naar gevonden resultaten
    - Specifieke verwijzing naar de oorzaak-gevolg schema's
    - Verwijzing naar het oorzaak-gevolg waarin je laat zien hoe jullie oplossing ingrijpt op terugkaatsing, isolatie en absorptie. (Geef dus in je oorzaak-gevolg schema aan op welke schakel de oplossing ingrijpt)
- Nette weergave van de resultaten
- Nette weergave van de oorzaak-gevolg schema's

Lesson 3

Bron1 Voeding & hartaanval

Wanneer je advies 3 (blz 50 van je tekstboek, afbeelding 16) niet opvolgt kan dit grote gevolgen hebben voor je gezondheid. Door veel verzadigde vetten te eten wordt de kans op een hartinfarct (hartaanval) vergroot. Bij een hartinfarct wordt een gedeelte van de kransslagader afgesloten. De kransslagader voorziet het hart van zuurstof en voedingsstoffen. Bij een hartinfarct krijgt het deel van het hart waar de verstopte slagader mee verbonden is, geen zuurstof en voedingsstoffen meer. Hierdoor sterft het gedeelte van het hart dat geen zuurstof meer krijgt af en hebben mensen last van pijn op de borst.

Als je voedsel eet met veel verzadigde vetten, wordt het net als gezond voedsel verteerd in je verteringskanaal. In je darmen wordt dit vet opgenomen in het bloed. Dit vet wordt in twee soorten pakketjes verpakt: HDL en LDL. LDL en HDL zijn vormen van cholesterol.

LDL is slecht cholesterol omdat dit cholesterol ervoor zorgt dat cholesterol van de lever naar de rest van het lichaam wordt getransporteerd. HDL is goed cholesterol, omdat dit ervoor zorgt dat er cholesterol naar de lever wordt getransporteerd. In de lever wordt het cholesterol afgebroken.

Er worden naar verhouding veel LDL pakketjes gemaakt en weinig HDL pakketjes, wanneer verzadigde vetten worden verteerd. Hierdoor wordt je gehalte LDL heel hoog in je bloed. Dit zorgt ervoor dat LDL zich gaat afzetten tegen de wand van bloedvaten, en dus ook in de kransslagader. Dit proces blijft net zo lang doorgaan, totdat het LDL gehalte van je bloed flink is gedaald. Wanneer dit gehalte hoog blijft, blijft LDL zich afzetten tegen de bloedvatwand. Er ontstaat dan een vernauwing van het bloedvat; een plaque (de berg zand).

Figuur 1 LDL transporteert cholesterol van de lever naar het lichaam, HDL brengt het overtollige cholesterol weer terug naar de lever. In de lever wordt het cholesterol afgebroken (http://www.hartwijzer.nl/LDL-cholesterol.php)

Het kan zijn dat een bepaalde gebeurtenis of bepaalde factoren ervoor zorgen dat de plaque scheurt. Als dit het geval is, zal het bloed in de buurt van de plaque gaan stollen, zodat er een bloedpropje ontstaat. Dit kun je vergelijken met wanneer je zelf een wondje hebt op je huid.

Het bloedpropje dat ontstaat sluit de kransslagader af. Hierdoor krijgt het deel van het hart waar de verstopte slagader mee verbonden is geen voedingsstoffen en zuurstof meer. We spreken op dit moment van een hartinfarct.

ANNEX 3 SURVEY QUESTIONS

Survey questions for students after the first lesson and expected answer to a certain research question

Question survey	Expected learning effect related to research questions
1. What do you think of today's biology lesson?	Motivational state of students. Not related to any research question
2. What do you think of cause-effect thinking? And give an argument for your opinion.	Motivational state of students. Not related to any research question
3. What did you learn today about cause-effect thinking?	Motivational state of students and let students put into words what they learned. Not related to any research question
4. Would you use cause-effect thinking again in another school subject, in your daily life, or during your follow-up study? Why?	Are students able to see the added value of making a CES. Research question 2.
5. Can you give another example of cause-effect thinking other than you heard today during class?	Are students able to think by their own of another example of cause-effect thinking? Research question 1

Survey questions for students after the third lesson

Question survey	Expected learning effect related to research questions
1. Is the example mentioned below an example of cause-effect thinking? And give an argument. Example: My dog is due in two weeks. According to the vet she gets three puppies.	Are students able to distinguish cause-effect relations from other relations? Research question 1 Are students able to mention criteria on which they base their distinction? Research question 1
2. Is the example mentioned below an example of cause-effect thinking? And give an argument. Example: Due to the fact that Misses ten Asbroek did not place her shoe in front of the stove, she did not get a present in her shoe for the fest of St Nicholas	Are students able to distinguish cause-effect relations from other relations? Research question 1 Are students able to mention criteria on which they base their distinction? Research question 1
3. Can you give another example of cause-effect thinking other than you heard in the lessons about cause-effect thinking? Indicate in your example the cause and effect.	Are students able to think by their own of another example of cause-effect thinking? Research question 1
4. If you had to explain to students form 2a or 2d how they can make a CES what would you tell them? Or what step-by-step plan would you recommend?	Are students able to apply cause-effect thinking consciously? (Criteria of Van Oers) Research question 1
5. Do you think that making a CES helps you learning? Give an argument	To what extent supports creating an CES learning? Research question 2
6. Would use make a CES for yourself during biology, physics of other classes?	Are students able to see the added value of making a CES. Research question 2.
7. Up to now you have made CES during biology and physic classes. Are the cause-effect situations in biology and physics different or the same? Give an argument and describe the differences and similarities.	See student's differences between cause-effect relations in biology classes and physic classes? Research question 3

Interview scheme teachers

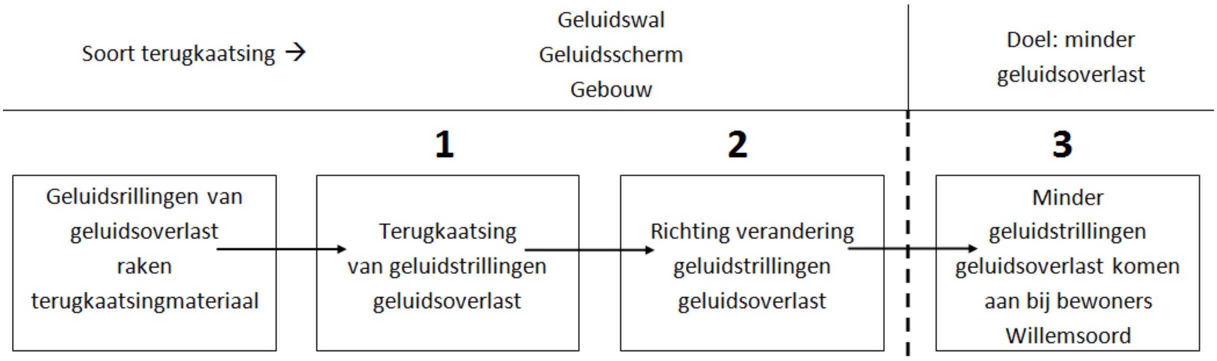
Question survey	Expected learning effect related to research questions
1. What did you think of the lesson?	Input to improve lesson materials about cause-effect thinking
2. Was it clear what was expected of you in teaching cause-effect thinking? What information was missing?	Input to improve lesson materials about cause-effect thinking
3. What are weaknesses and strengths of the lesson about cause-effect thinking? What points can be improved?	Input to improve lesson materials about cause-effect thinking
4. How did students work during class?	Input to improve lesson materials about cause-effect thinking
5. Do you think that students learned better/more effective about food poisoning/reflection, absorption and insulation/heart attack, due to cause-effect thinking?	To what extent supports creating an OGS learning? Research question 2
6. Are the cause-effect situations in biology and physics different or the same? Give an argument and describe the differences and similarities	See teacher's differences between cause-effect relations in biology classes and physic classes? Research question 3

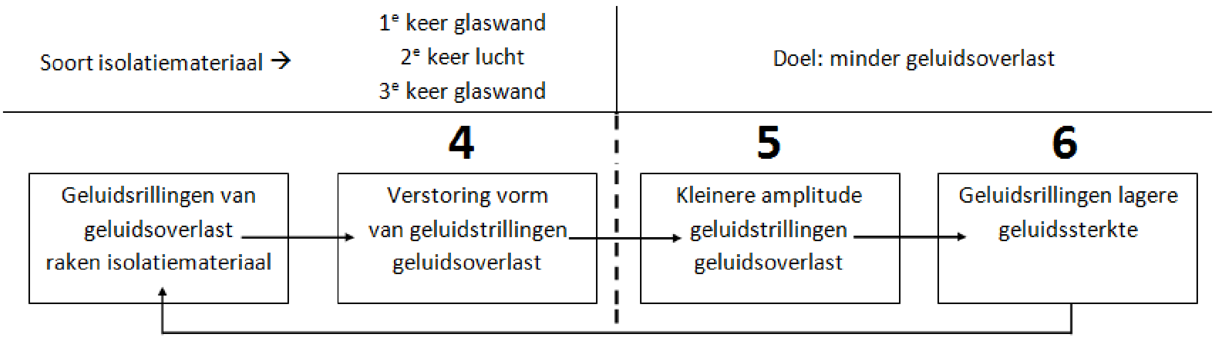
ANNEX 4 OBSERVATION FORM

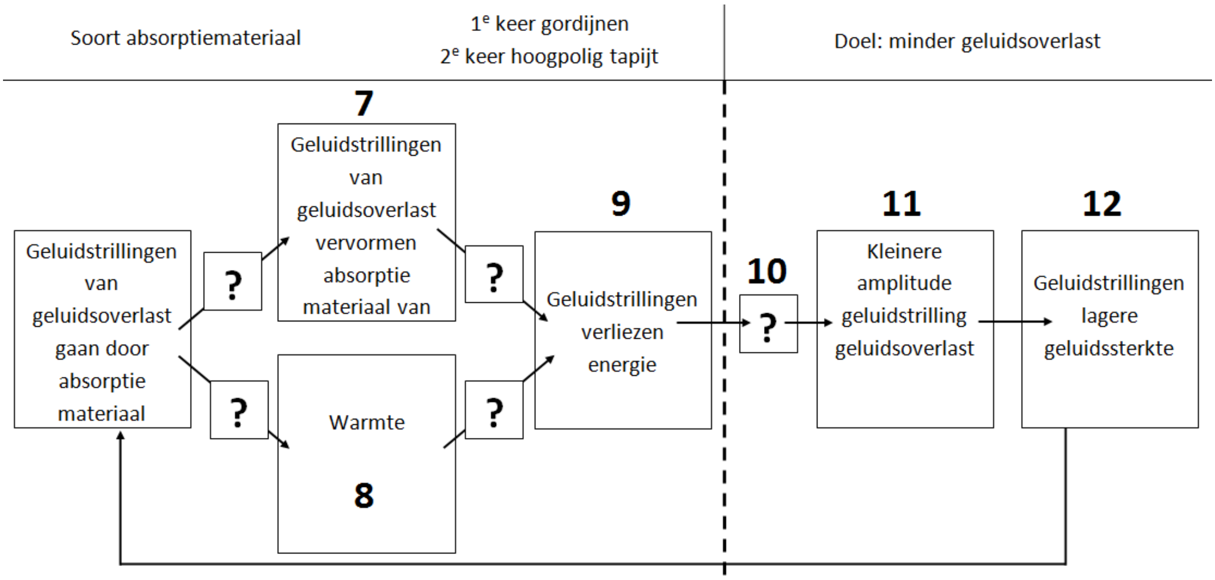
Soort opmerking: V: verduidelijking E: ervaring I:inhoud OGR: oorzaak-gevolg redenatie 2b bio(1)

Tijd	Soort opmerking	Opmerking/bijzondere gebeurtenis
9.10		
9.15		
9.20		

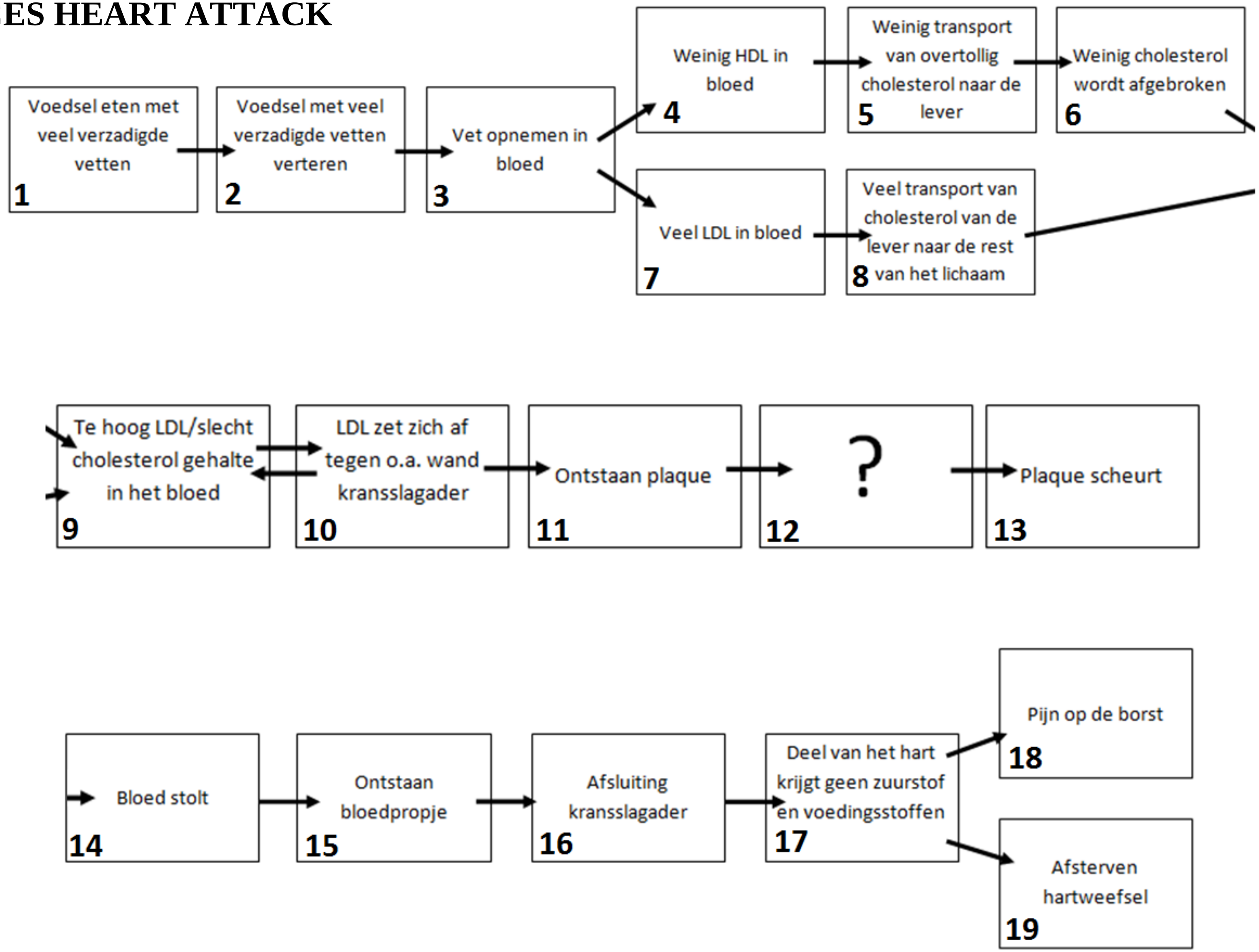
ANNEX 5 CES REFLECTION, ABSORPTION AND INSULATION



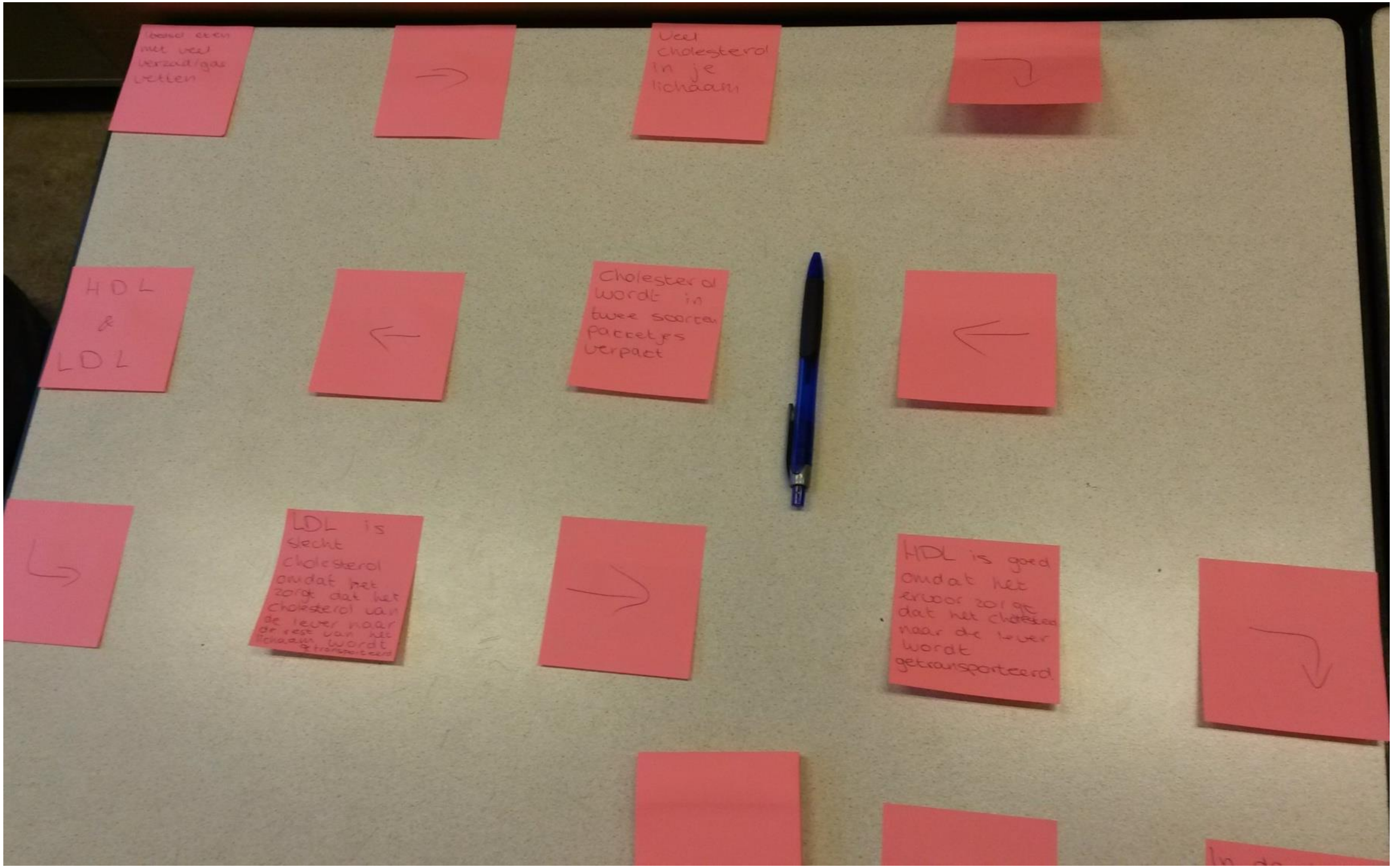


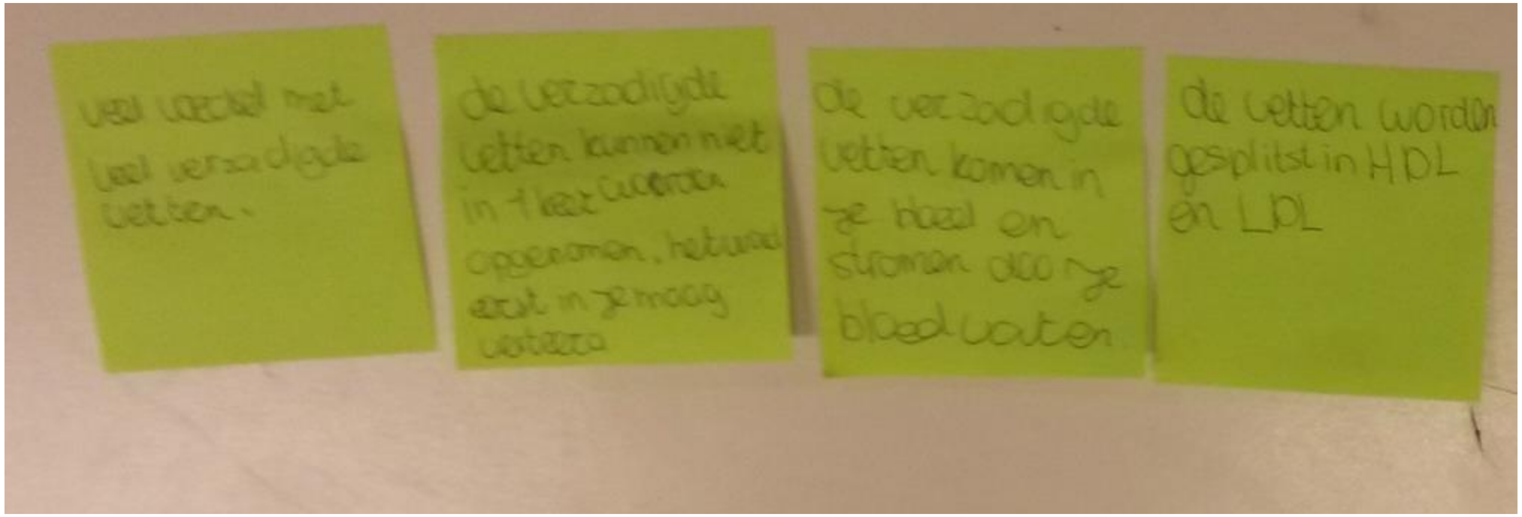


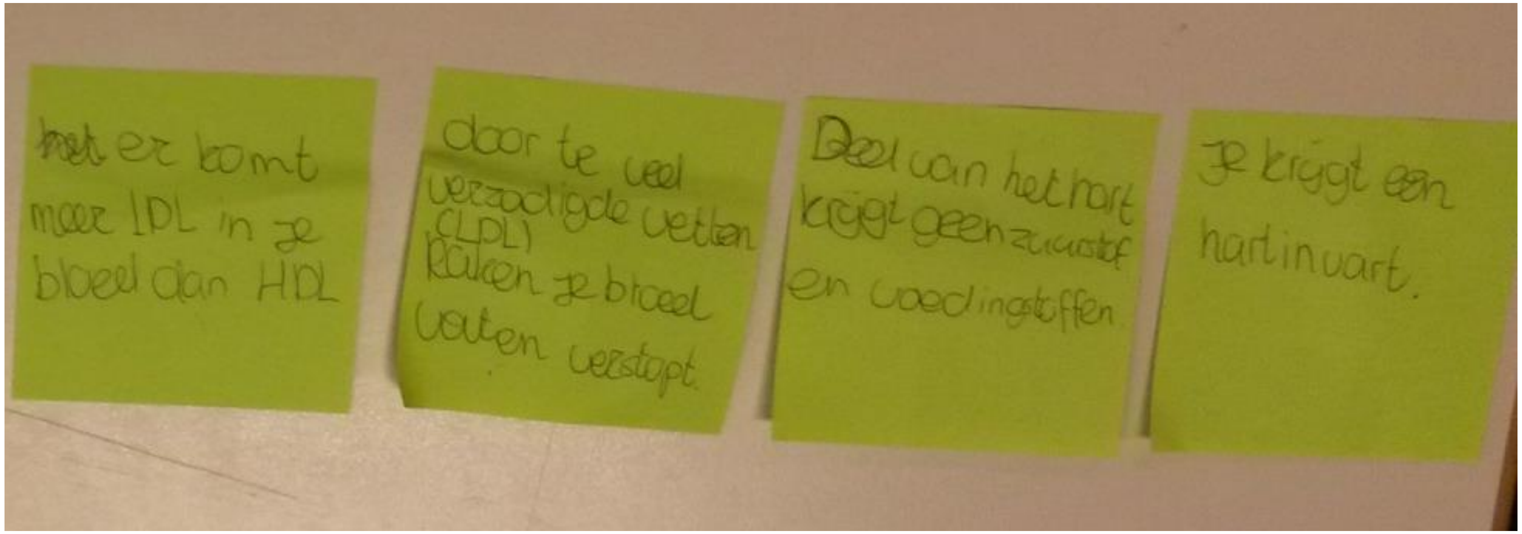
ANNEX 6 CES HEART ATTACK

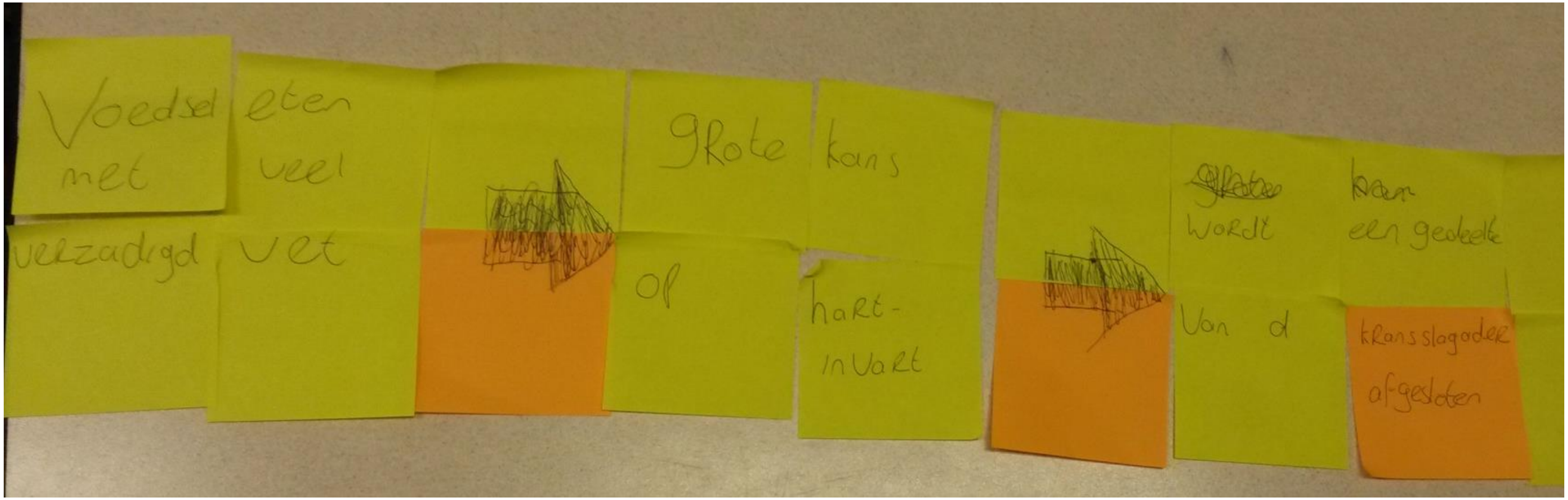


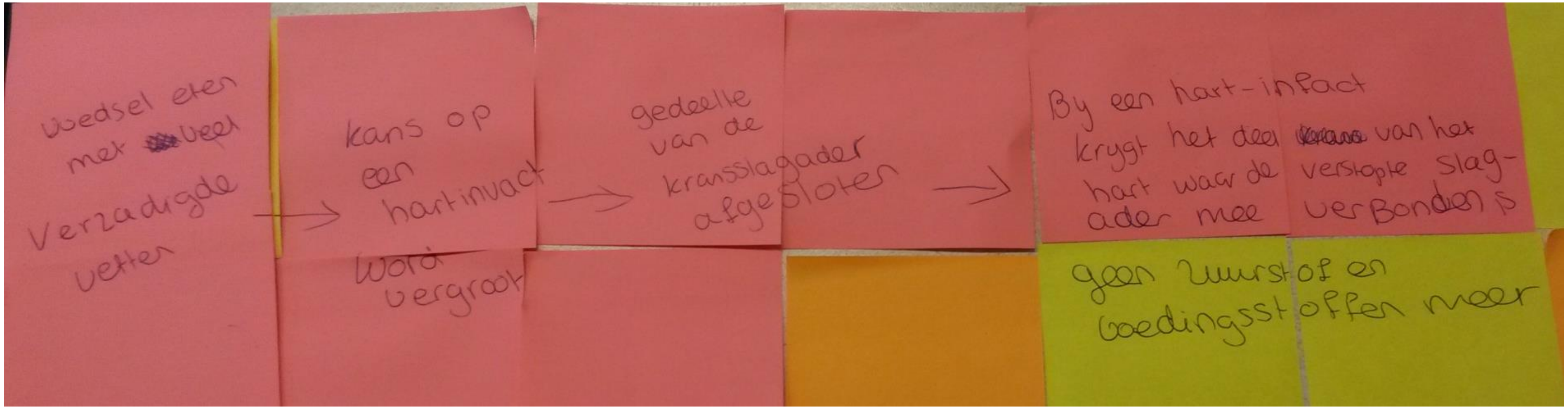
ANNEX 7 STUDENTS CES HEART ATTACK

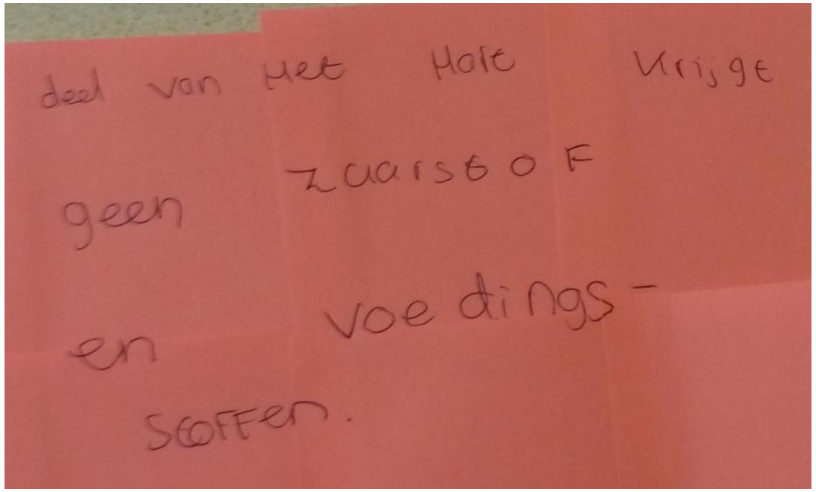


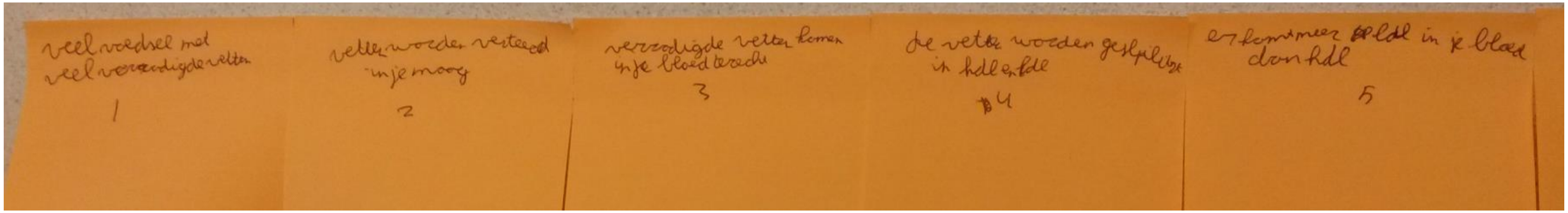

veel voedsel met veel verzadigde vetten.
de verzadigde vetten kunnen niet in 1 keer worden opgenomen, het word
de verzadigde vetten komen in je bloed en stromen door je bloedvaten
de vetten worden gesplitst in HDL en LDL

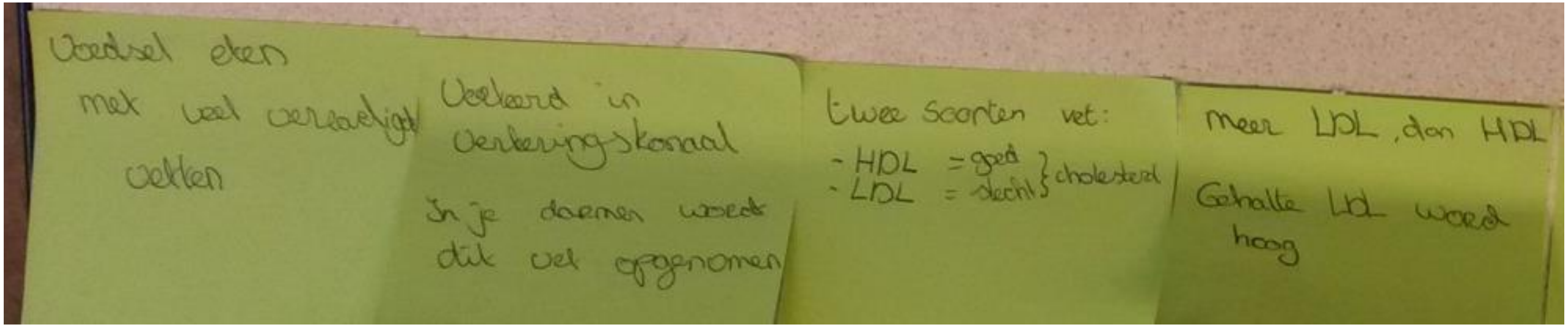

er komt meer LDL in je bloed dan HDL
door te veel verzadigde vetten (LDL) raken je bloedvaten verstopt.
Deel van het hart krijgt geen zuurstof en voedingstoffen
Je krijgt een hartinvart.

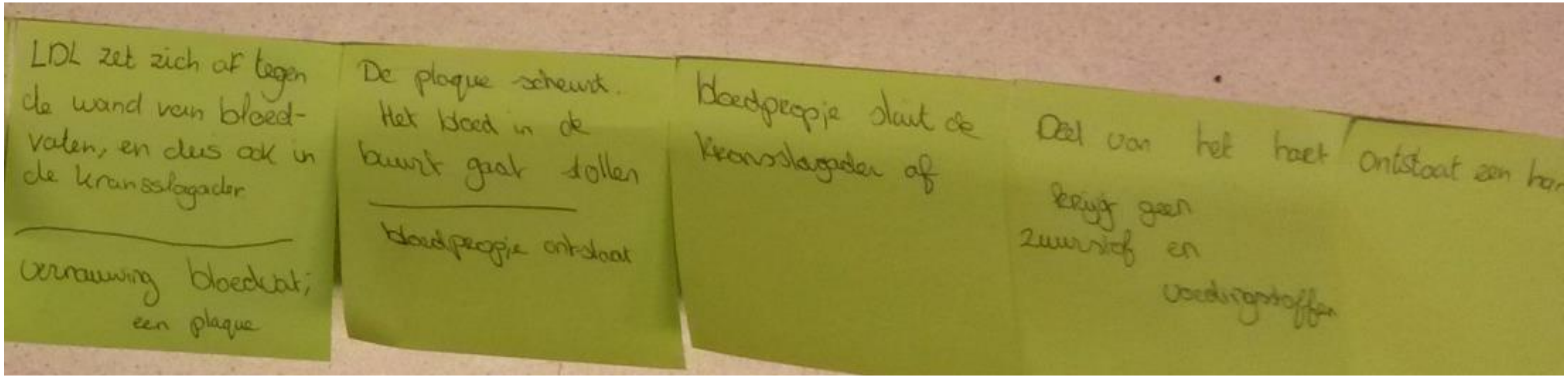

Voedsel eten
met veel
verzadigd vet
grote kans
op
hart-
inVart
wordt
een gedeelte
Van d
kransslagader
afgesloten

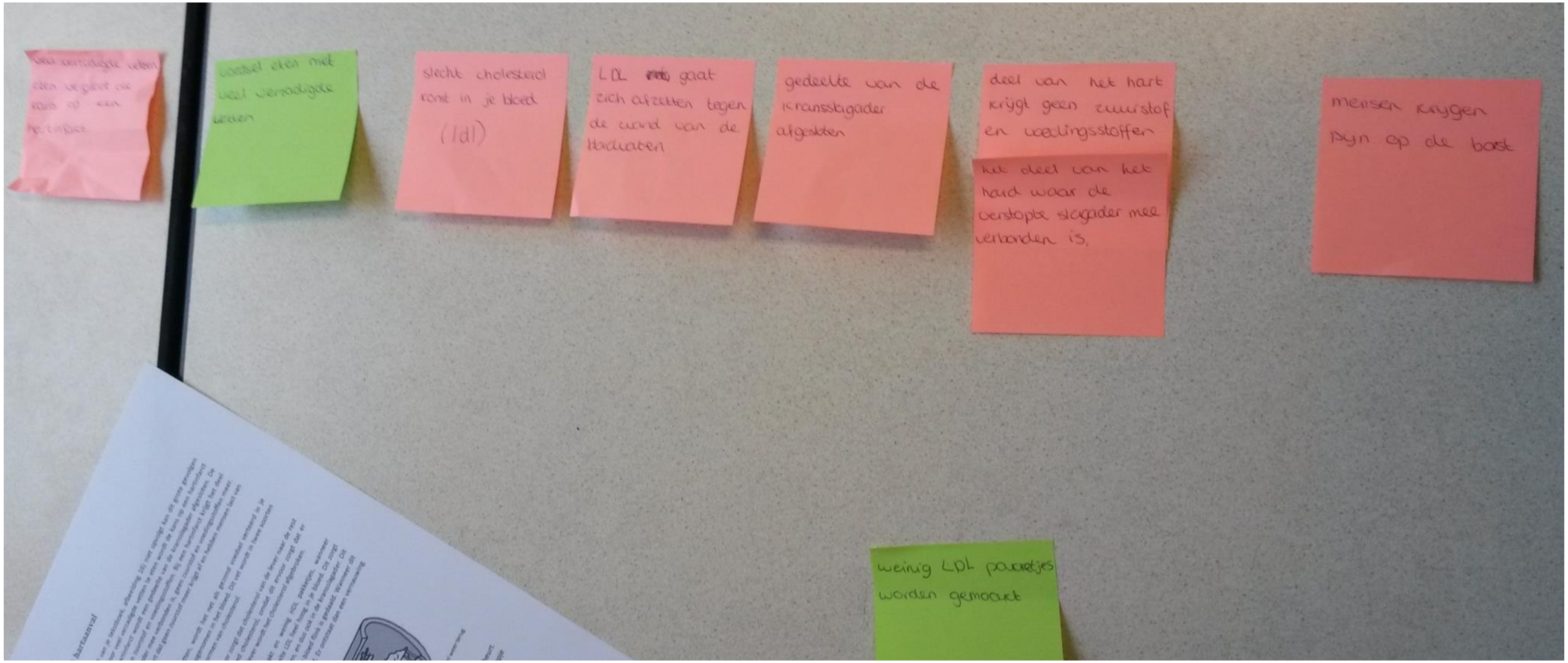

voedsel eten
met veel
Verzadigde
vetten
kans op
een
hartinvact
word
vergroot
gedeelte
van de
kransslagader
afgesloten
By een hart-infact
krygt het deel van het
hart waar de verstopte slag-
ader mee verBonden is
geen zuurstof en
voedingsstoffen meer

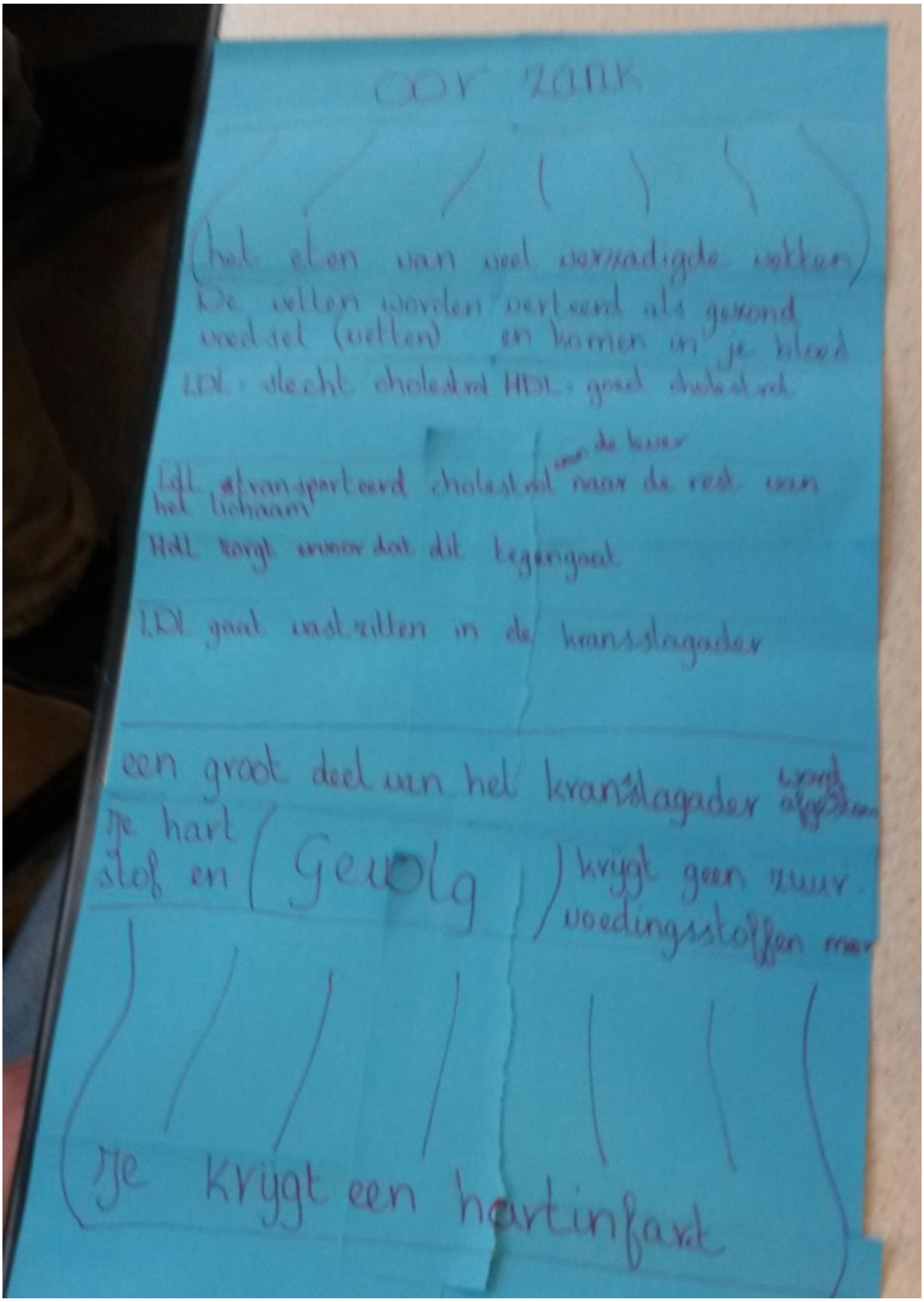

deel van het Hart krijgt
geen zuurstof
en voedings-
stoffen.

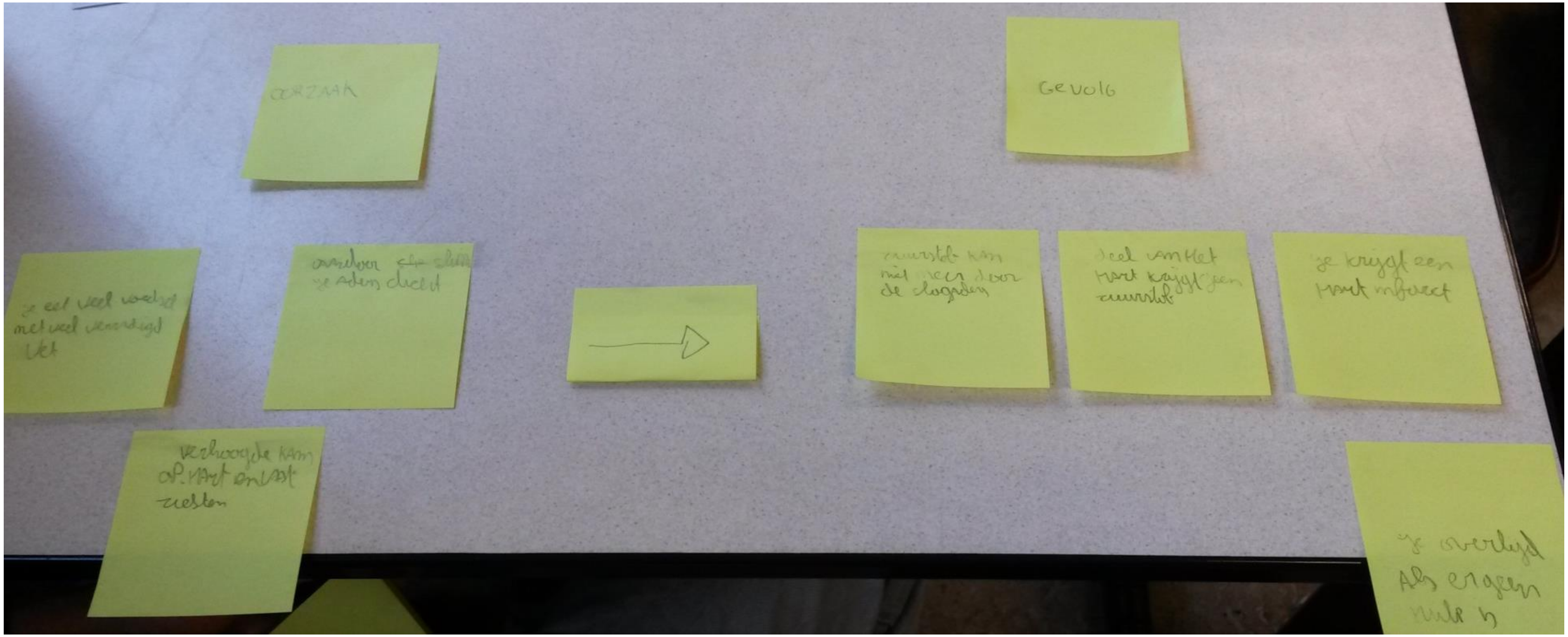

veel voedsel met veel verzadigde vetten
1
vetten worden verteerd in je maag
2
verzadigde vetten komen in je bloed terecht
3
de vetten worden gesplitst in hdl en ldl
4
er komt meer ldl in je bloed dan hdl
5

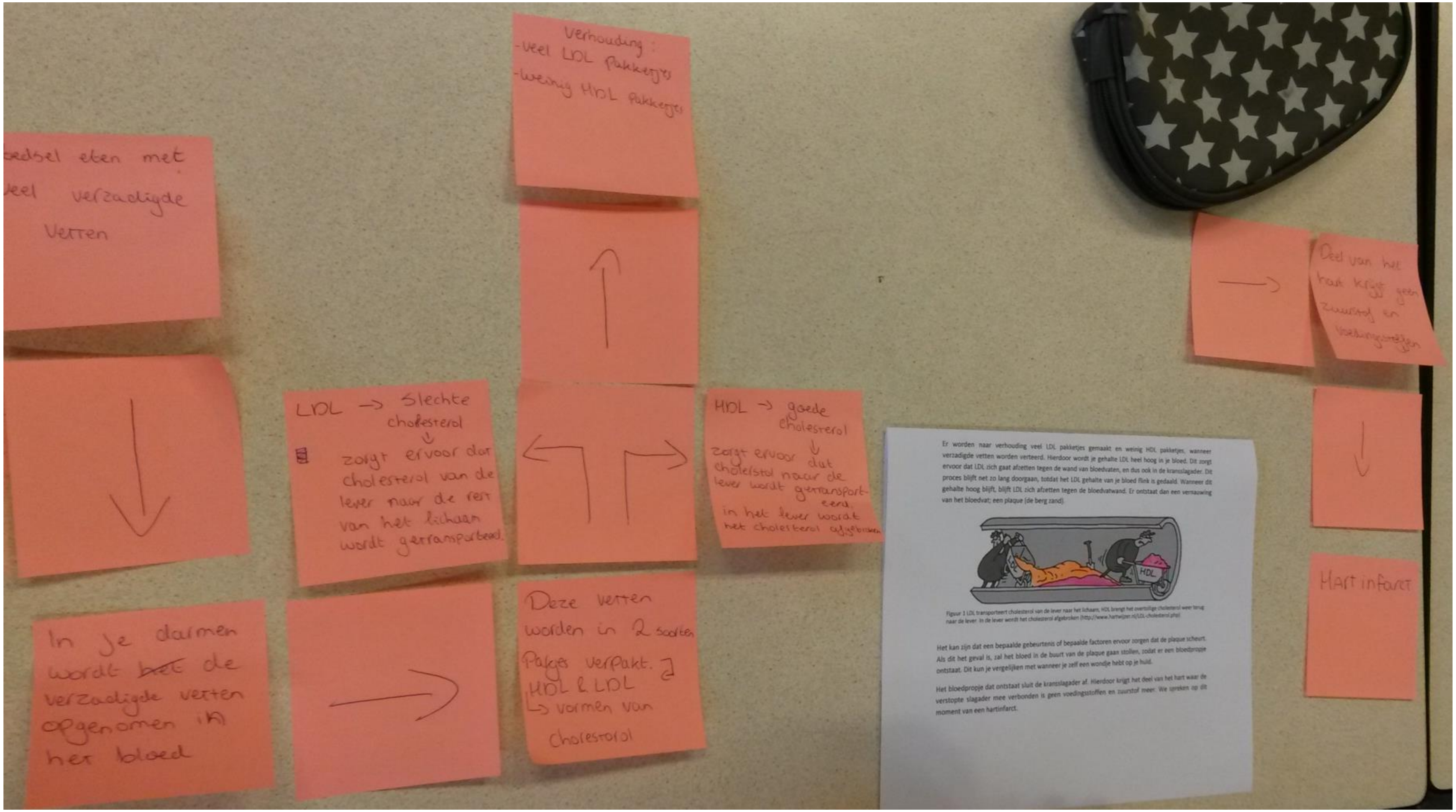

Voedsel eten met veel verzadigd vetten
Verkeerd in verteringskanaal
In je darmen wordt dit vet opgenomen
Twee soorten vet:
- HDL = goed
- LDL = slecht
} cholesterol
Meer LDL, dan HDL
Gehalte LDL wordt hoog

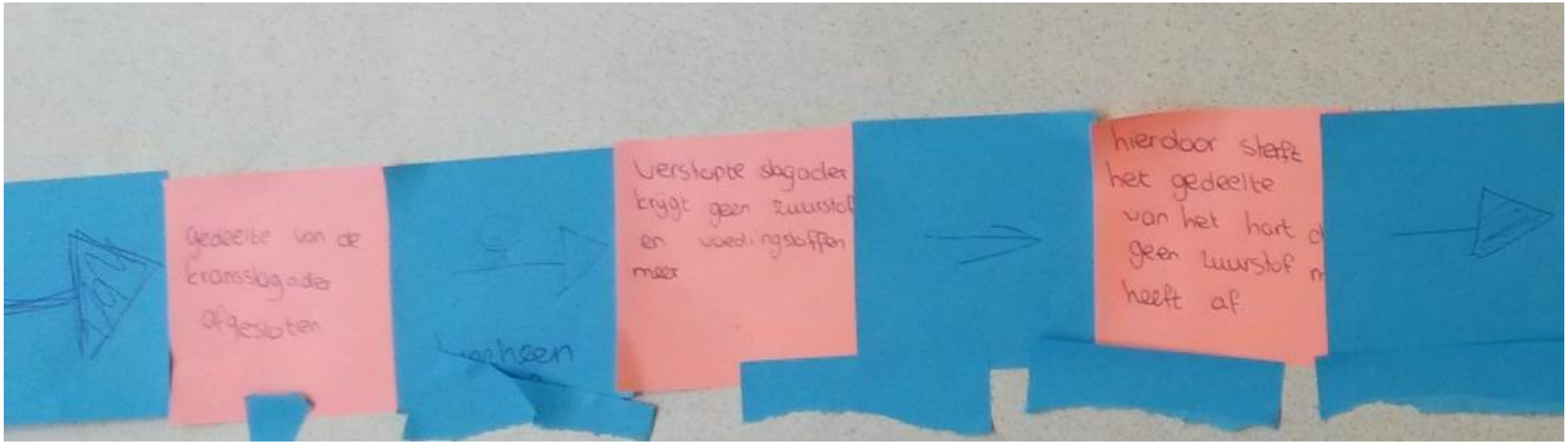

LDL zet zich af tegen de wand van bloedvaten, en dus ook in de kransslagader
vernauwing bloedvat; een plaque
De plaque scheurt. Het bloed in de buurt gaat stollen
bloedpropje ontstaat
bloedpropje sluit de kransslagader af
Deel van het hart krijgt geen zuurstof en voedingsstoffen
Ontstaat een har

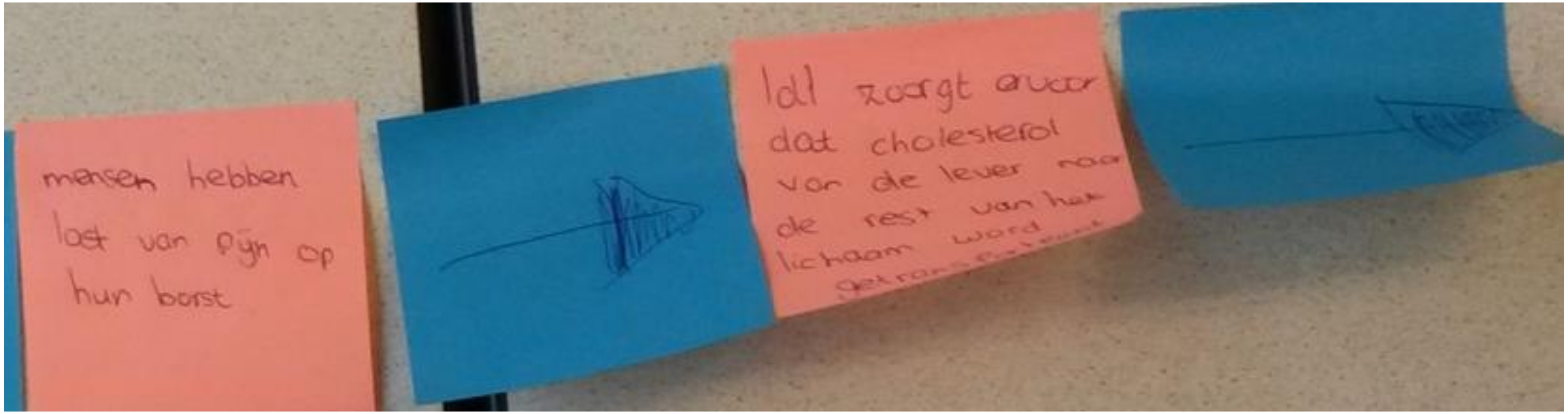

voedsel eten met veel verzadigde vetten
slecht cholesterol komt in je bloed
(ldl)
LDL gaat zich afzetten tegen de wand van de bloedvaten
gedeelte van de kransslagader afgesloten
deel van het hart krijgt geen zuurstof en voedingsstoffen
het deel van het hard waar de verstopte slagader mee verbonden is,
mensen krijgen pijn op de borst
weinig LDL pakketjes worden gemaakt

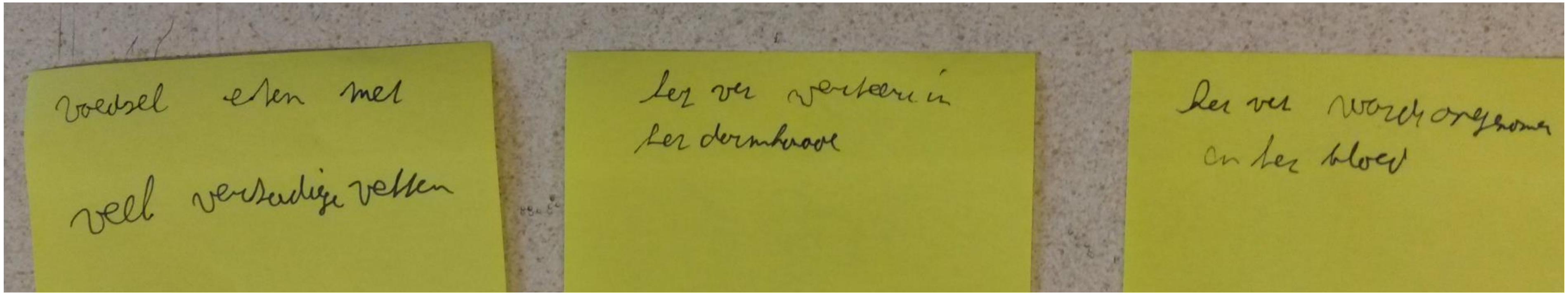

oorzaak
het eten van veel verzadigde vetten
De vetten worden verteerd als gezond voedsel (vetten) en komen in je bloed
LDL: slecht cholesterol HDL: goed cholesterol
LDL transporteerd cholesterol van de lever naar de rest van het lichaam
LDL gaat vastzitten in de kransslagader
een groot deel van het kransslagader
je hart
krijgt geen zuurstof en voedingsstoffen meer
Gevolg
je krijgt een hartinfarct

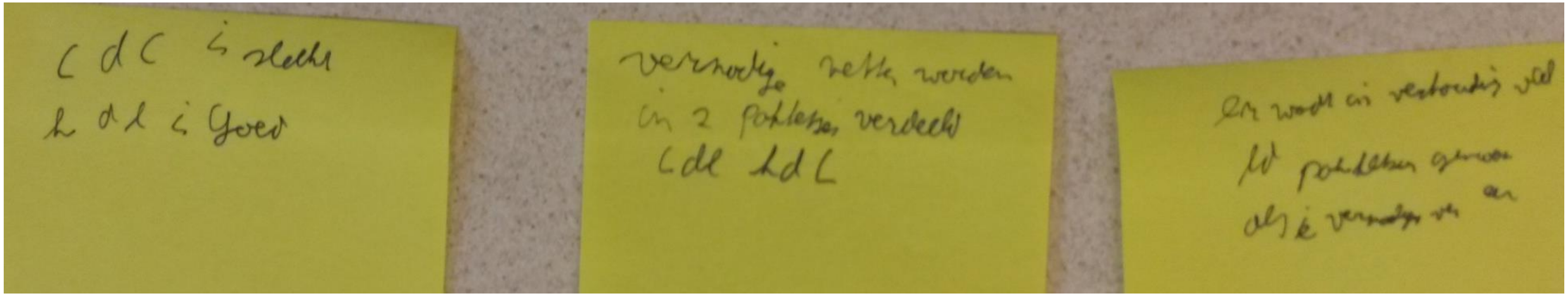

OORZAAK
GEVOLG
je krijgt een hart infarct

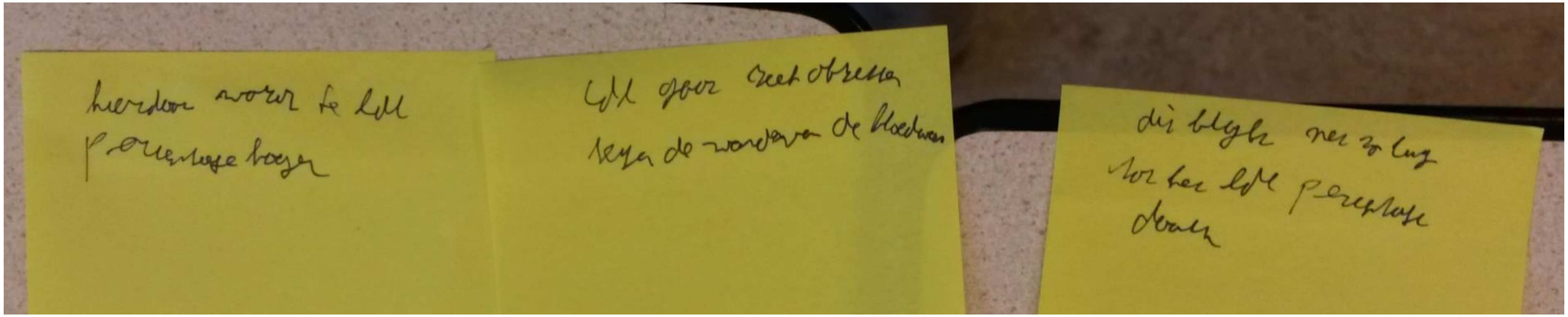

oedsel eten met
eel verzadigde
vetten
In je darmen wordt bret de verzadigde vetten opgenomen in het bloed
Deze vetten worden in 2 soorten pakjes verpakt.
HDL & LDL
↳ vormen van cholesterol
Verhouding:
-veel LDL pakketjes
-weinig HDL pakketjes
LDL → slechte cholesterol
zorgt ervoor dat cholesterol van de lever naar de rest van het lichaam wordt getransporteerd.
HDL → goede cholesterol
zorgt ervoor dat cholesterol naar de lever wordt getransporteerd.
in het lever wordt het cholesterol afgebroken
Er worden naar verhouding veel LDL pakketjes gemaakt en weinig HDL pakketjes, wanneer verzadigde vetten worden verteerd. Hierdoor wordt je gehalte LDL heel hoog in je bloed. Dit zorgt ervoor dat LDL zich gaat afzetten tegen de wand van bloedvaten, en dus ook in de kransslagader. Dit proces blijft net zo lang doorgaan, totdat het LDL gehalte van je bloed flink is gedaald. Wanneer dit gehalte hoog blijft, blijft LDL zich afzetten tegen de bloedvatwand. Er ontstaat dan een vernauwing van het bloedvat; een plaque (de berg zand).
LDL
HDL
Figuur 1 LDL transporteert cholesterol van de lever naar het lichaam, HDL brengt het overtollige cholesterol weer terug naar de lever. In de lever wordt het cholesterol afgebroken
Het kan zijn dat een bepaalde gebeurtenis of bepaalde factoren ervoor zorgen dat de plaque scheurt. Als dit het geval is, zal het bloed in de buurt van de plaque gaan stollen, zodat er een bloedpropje ontstaat. Dit kun je vergelijken met wanneer je zelf een wondje hebt op je huid.
Het bloedpropje dat ontstaat sluit de kransslagader af. Hierdoor krijgt het deel van het hart waar de verstopte slagader mee verbonden is geen voedingsstoffen en zuurstof meer. We spreken op dit moment van een hartinfarct.
Deel van het hart krijgt geen zuurstof en voedingsstoffen
Hart infarct

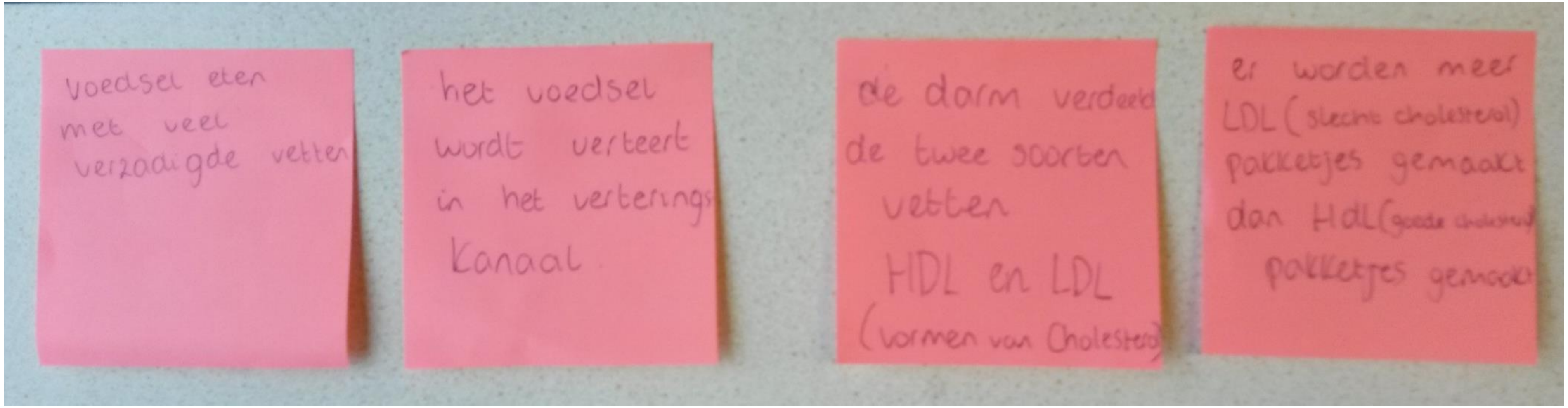

gedeelte van de
kransslagader
afgesloten
verstopte slagader
krijgt geen zuurstof
en voedingsstoffen
meer
hierdoor sterft
het gedeelte
van het hart
geen zuurstof
heeft af

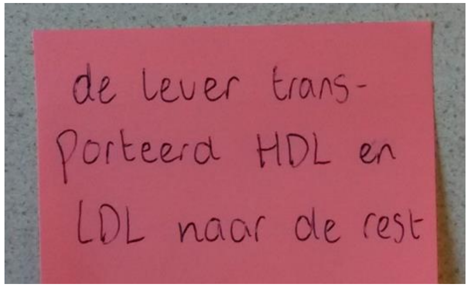

mensen hebben
last van pijn op
hun borst
ldl zorgt ervoor
dat cholesterol
var de lever naar
de rest van het
lichaam word

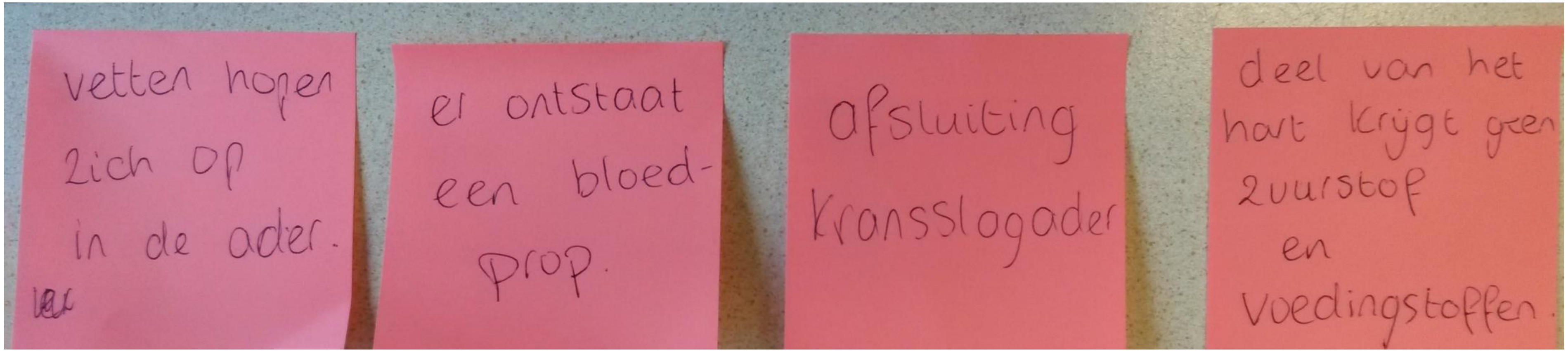

voedsel eten met
veel verzadigde vetten
het vet verteert in
het darmkanaal
het vet wordt opgenomen
in het bloed

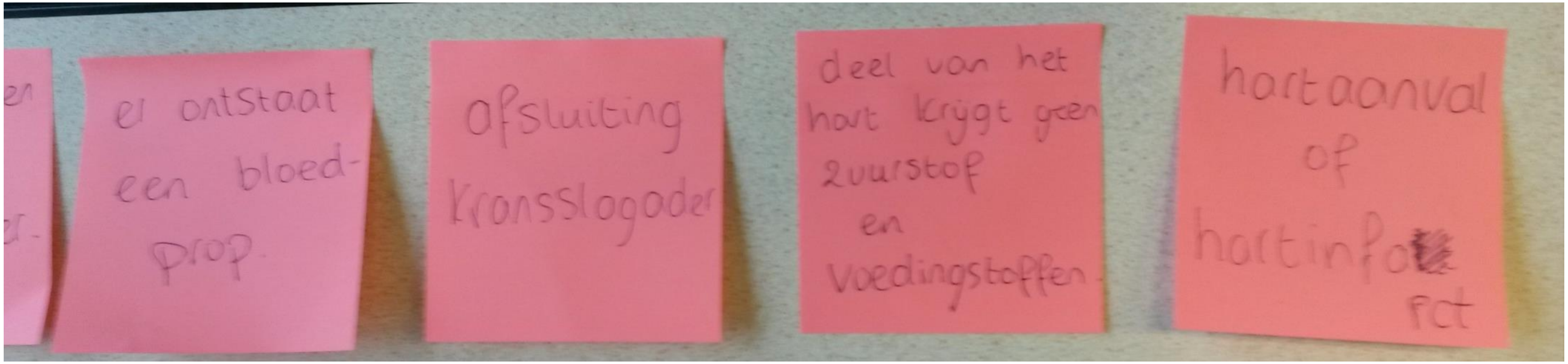

LDL is slecht
HDL is goed
LDL HDL

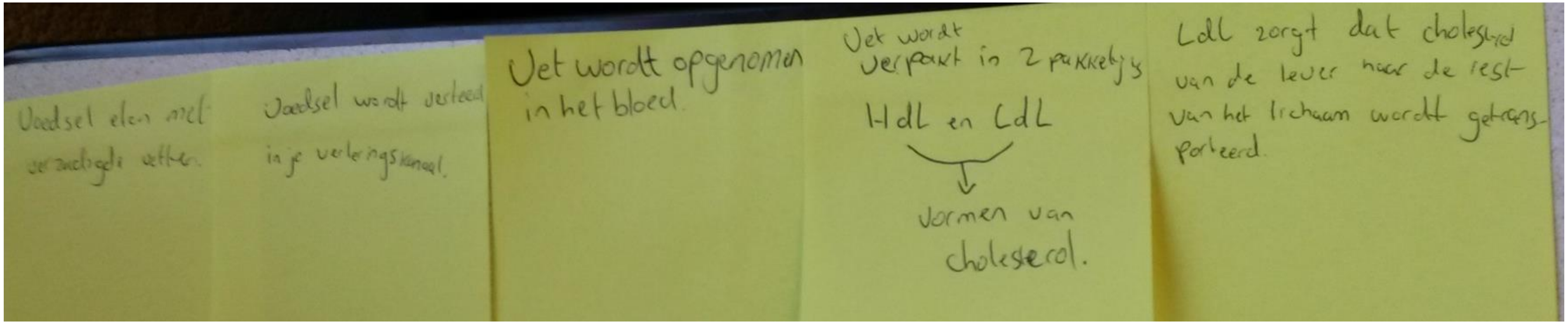


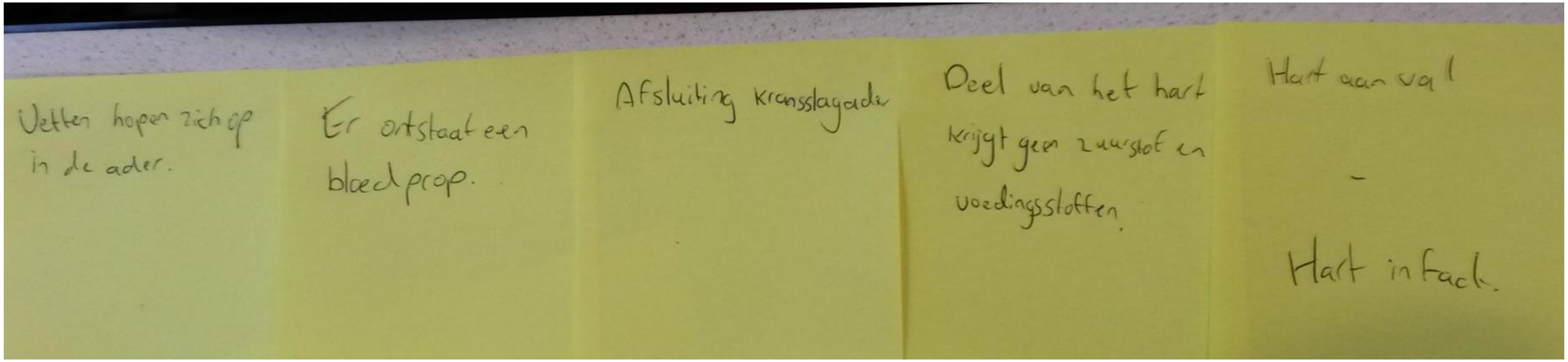

voedsel eten met veel verzadigde vetten
het voedsel wordt verteert in het verterings kanaal
de darm verdeelt de twee soorten vetten HDL en LDL (vormen van Cholesterol)
er worden meer LDL (slecht cholesterol) pakketjes gemaakt dan HDL (goede cholesterol) pakketjes gemaakt

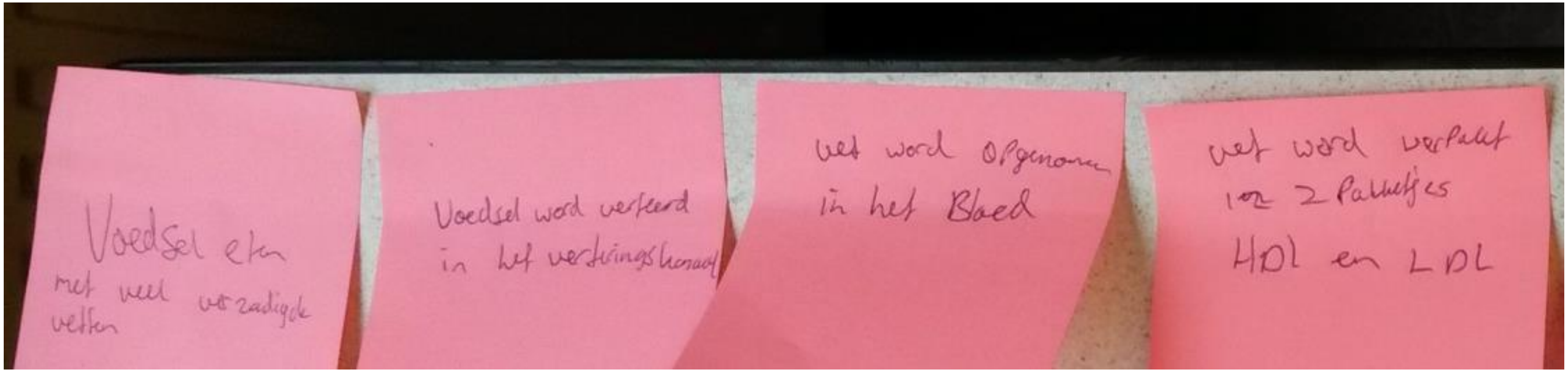

de lever trans-porteerd HDL en LDL naar de rest

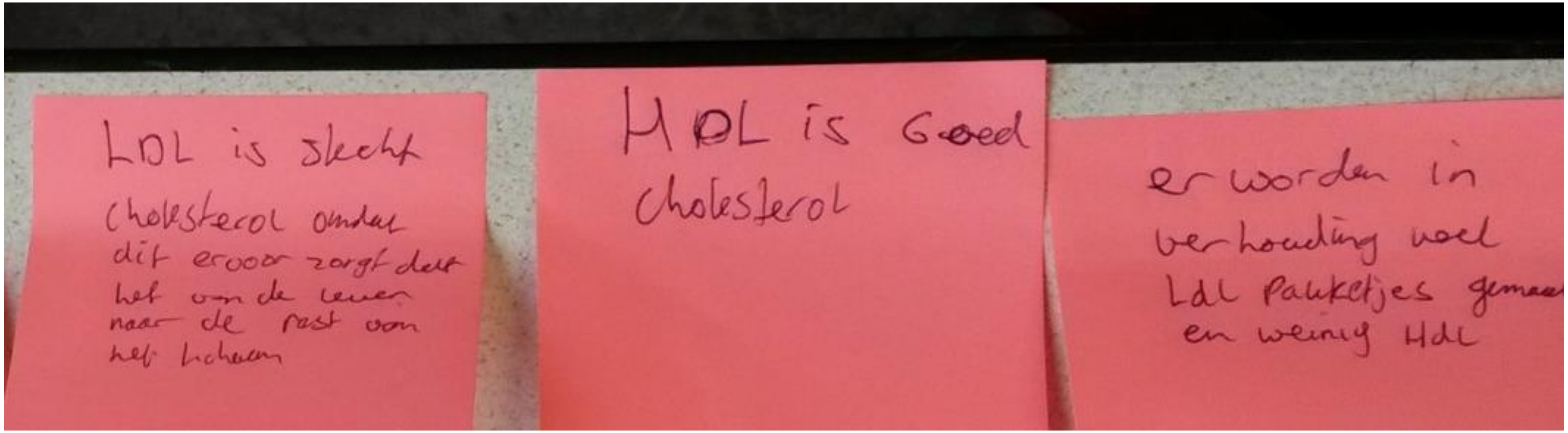

vetten hopen zich op in de ader.
er ontstaat een bloed-prop.
afsluiting Kransslagader
deel van het hart krijgt geen zuurstof en voedingstoffen.

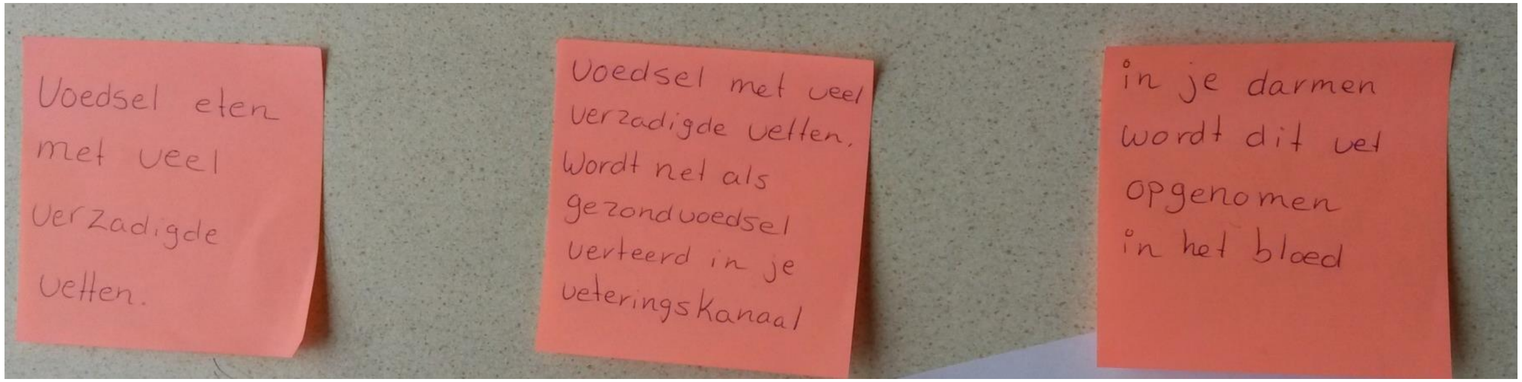

el ontstaat een bloed- prop.
afsluiting kransslagader
deel van het hart krijgt geen zuurstof en voedingstoffen.
hartaanval of hartinfarct

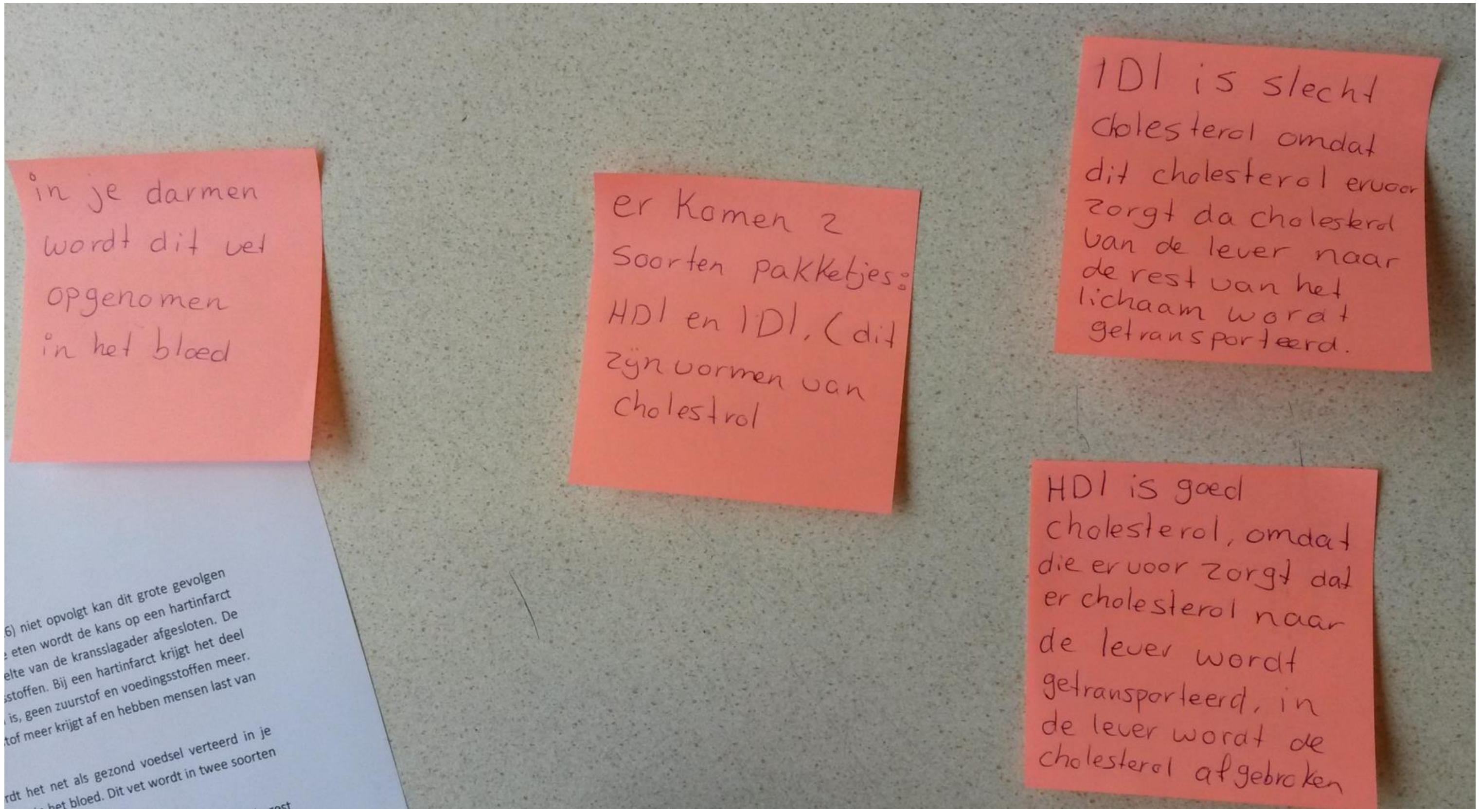

Voedsel eten met verzadigde vetten.
Voedsel wordt verteerd in je verteringskanaal.
Vet wordt opgenomen in het bloed.
Vet wordt verpakt in 2 pakketjes
HdL en LdL
vormen van cholesterol.
LdL zorgt dat cholesterol van de lever naar de rest van het lichaam wordt getransporteerd.

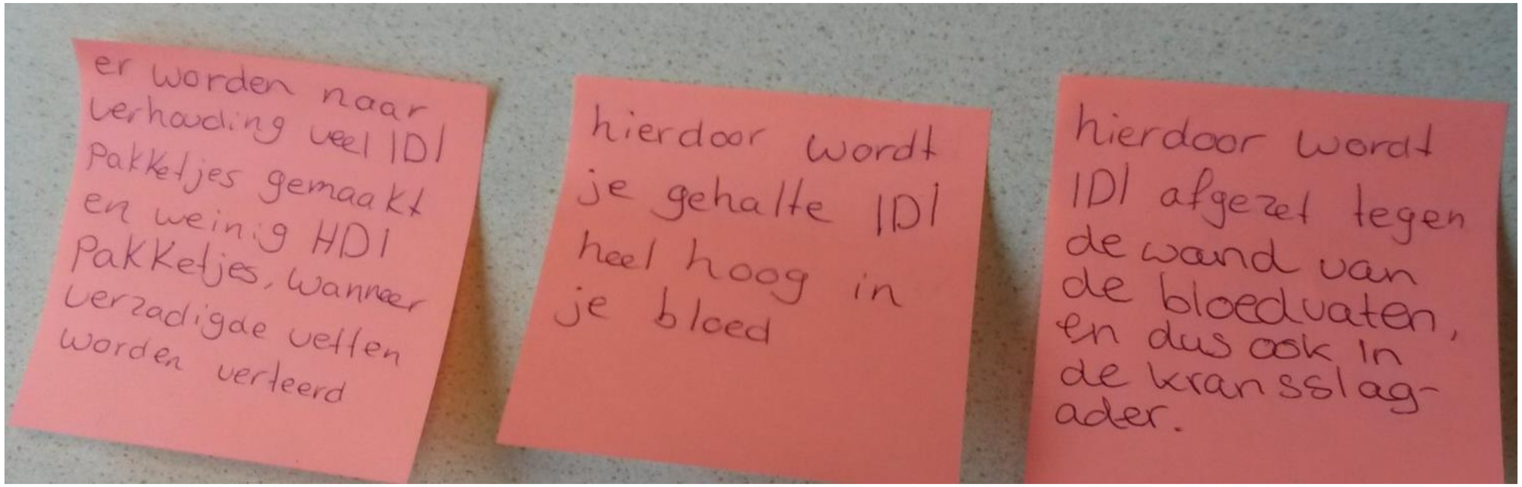

Vetten hopen zich op in de ader.
Er ontstaat een bloedprop.
Afsluiting kransslagader
Deel van het hart krijgt geen zuurstof en voedingsstoffen.
Hart aanval
-
Hart infack.

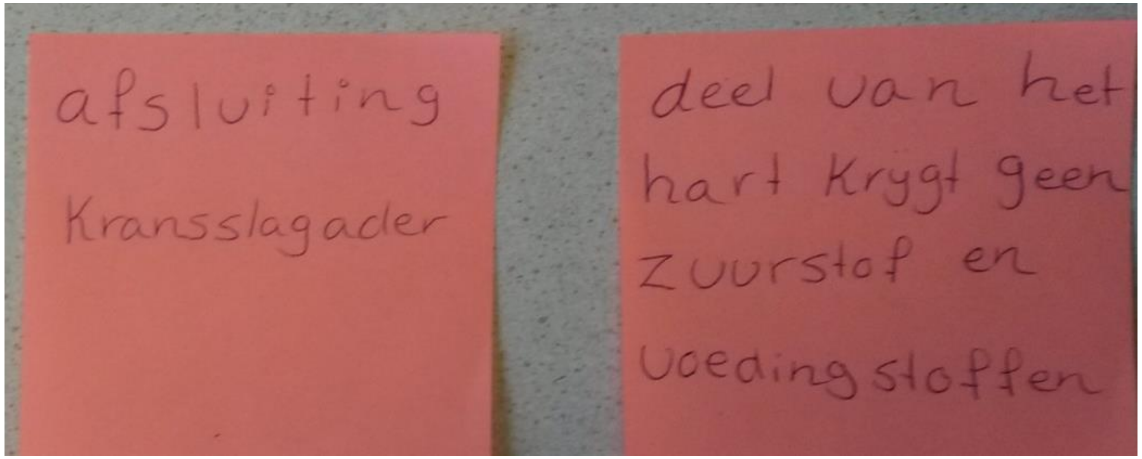

Voedsel eten
met veel verzadigde vetten
Voedsel word verteerd
in het verteringskanaal
vet word opgenomen
in het Bloed
vet word verpakt
2 pakketjes
HDL en LDL

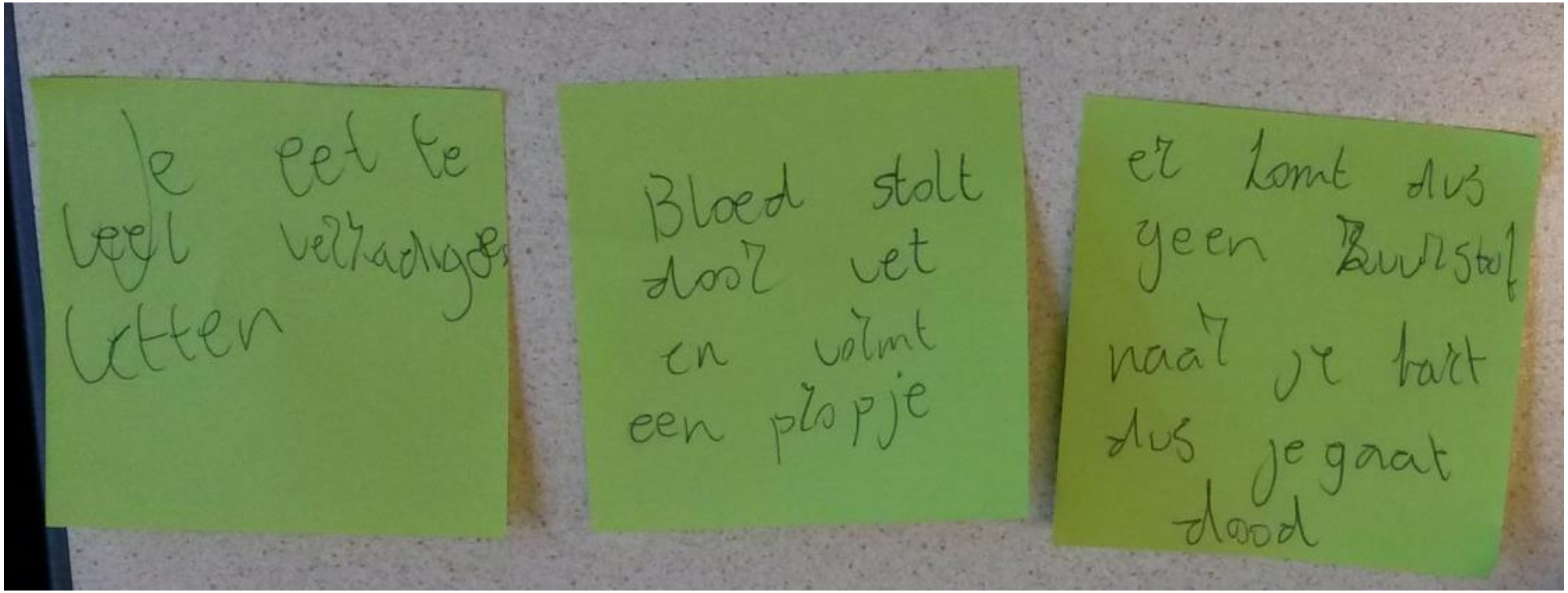

LDL is slecht
cholesterol omdat
dit ervoor zorgt dat
het van de lever
naar de rest van
het lichaam
HDL is Goed
cholesterol
er worden in
verhouding veel
LDL pakketjes
en weinig HDL

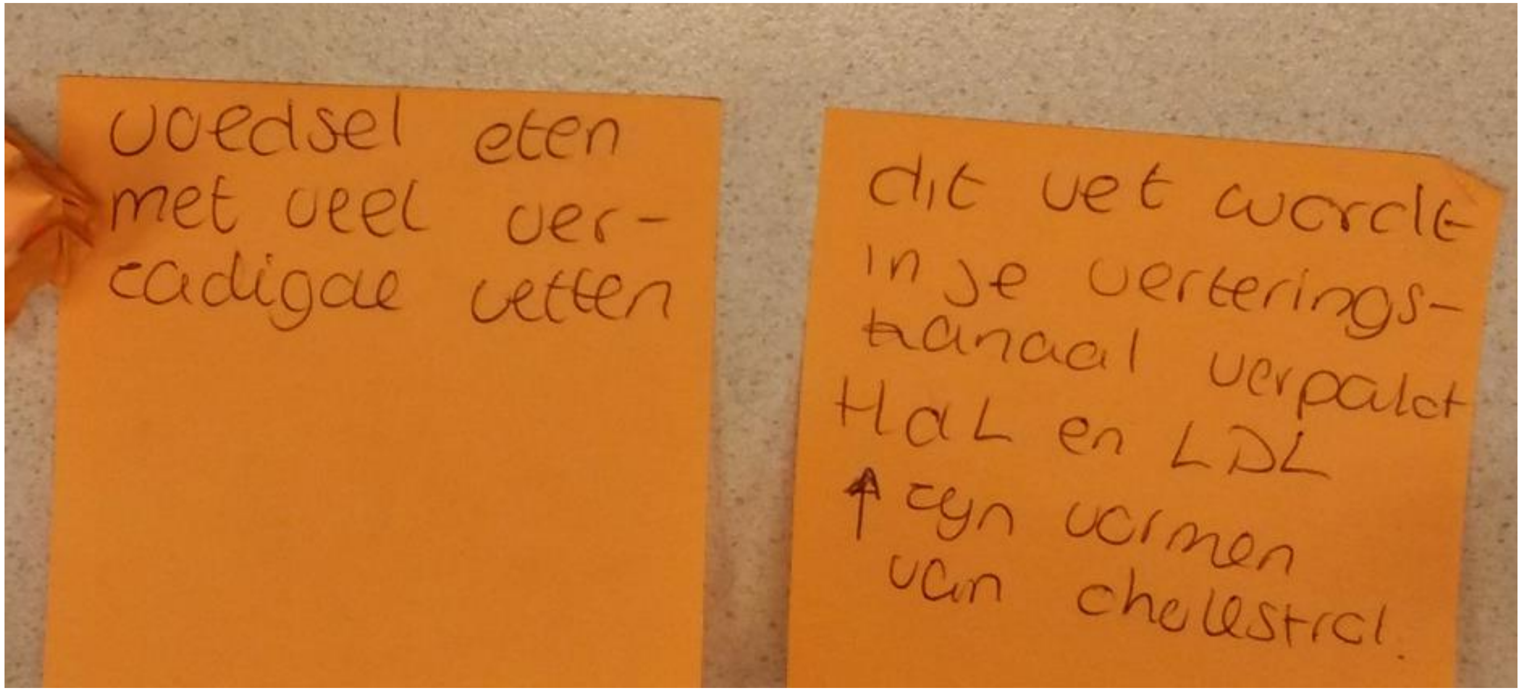

Voedsel eten met veel verzadigde vetten.
Voedsel met veel verzadigde vetten, Wordt net als gezondvoedsel verteerd in je veteringskanaal
in je darmen wordt dit vet opgenomen in het bloed

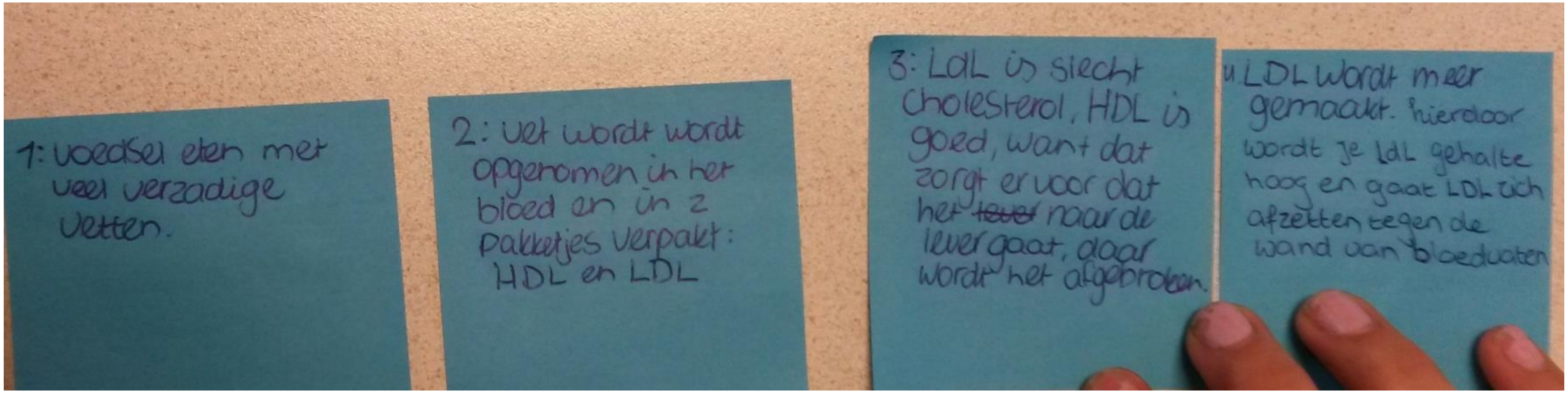

in je darmen wordt dit vet opgenomen in het bloed
er komen 2 soorten pakketjes: HDl en lDl, (dit zijn vormen van cholestrol
lDl is slecht cholesterol omdat dit cholesterol ervoor zorgt da cholesterol van de lever naar de rest van het lichaam wordt getransporteerd.
HDl is goed cholesterol, omdat die ervoor zorgt dat er cholesterol naar de lever wordt getransporteerd, in de lever wordt de cholesterol afgebroken
6) niet opvolgt kan dit grote gevolgen
eten wordt de kans op een hartinfarct
elte van de kransslagader afgesloten. De
stoffen. Bij een hartinfarct krijgt het deel
is, geen zuurstof en voedingsstoffen meer.
tof meer krijgt af en hebben mensen last van
rdt het net als gezond voedsel verteerd in je
het bloed. Dit vet wordt in twee soorten

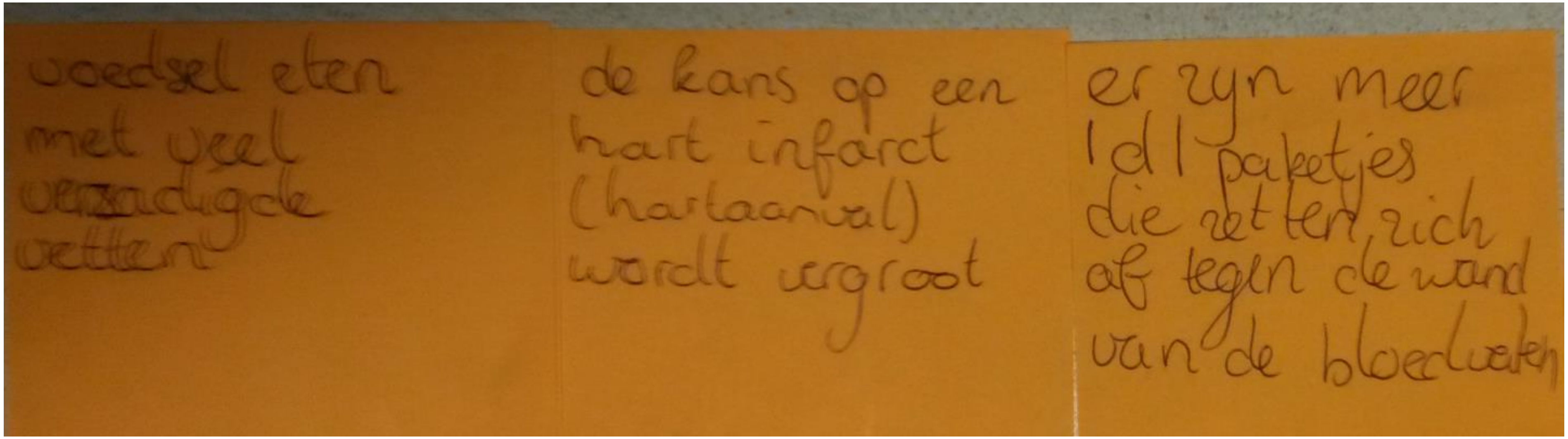

er worden naar verhouding veel ldl pakketjes gemaakt en weinig HDl pakketjes, wanneer verzadigde vetten worden verteerd
hierdoor wordt je gehalte ldl heel hoog in je bloed
hierdoor wordt ldl afgezet tegen de wand van de bloedvaten, en dus ook in de kransslag-ader.

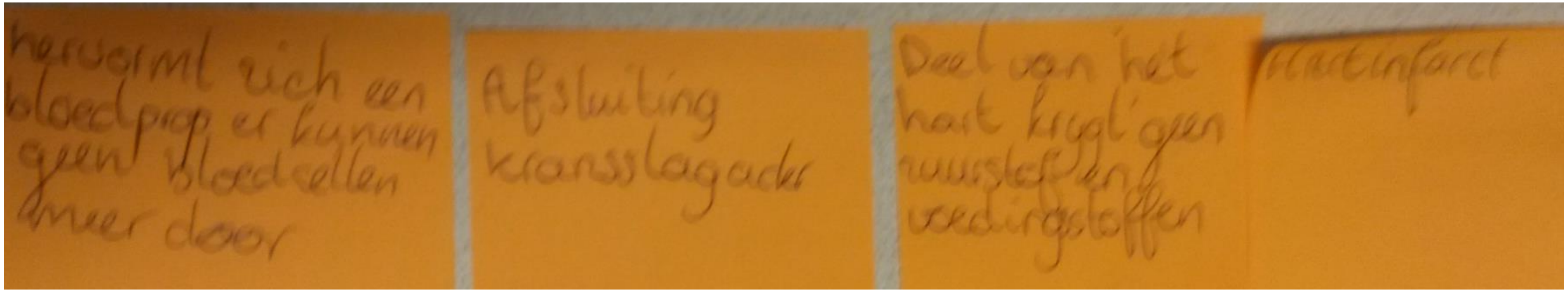

afsluiting Kransslagader
deel van het hart krijgt geen zuurstof en voedingstoffen

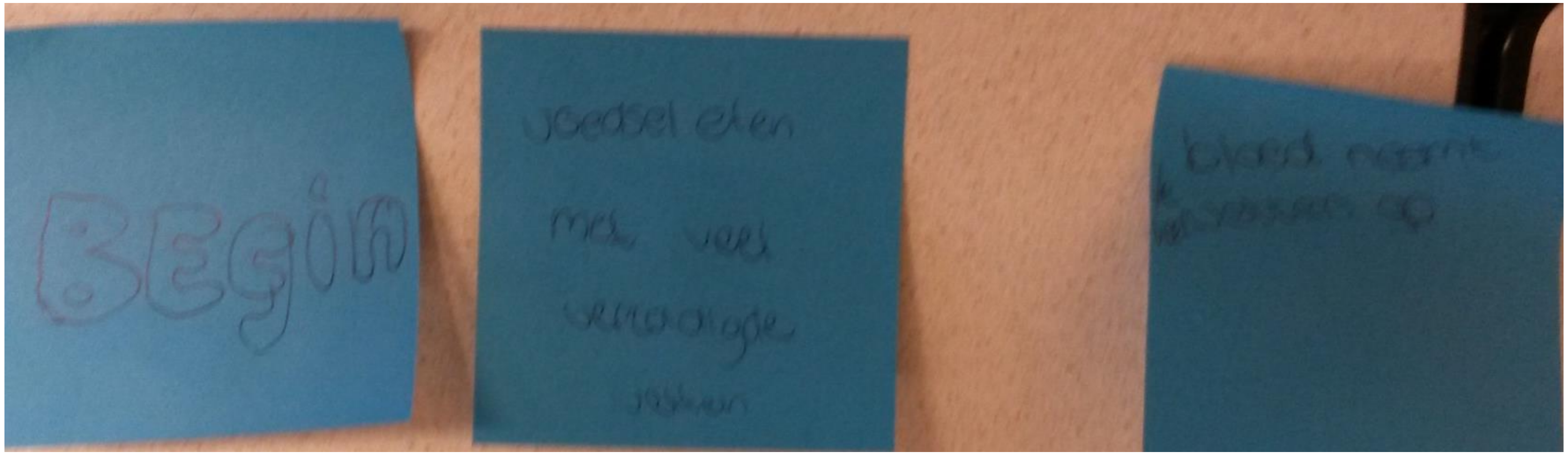

Je eet te veel verzadigde vetten
Bloed stolt door vet en vormt een propje
er komt dus geen zuurstof naar je hart dus je gaat dood

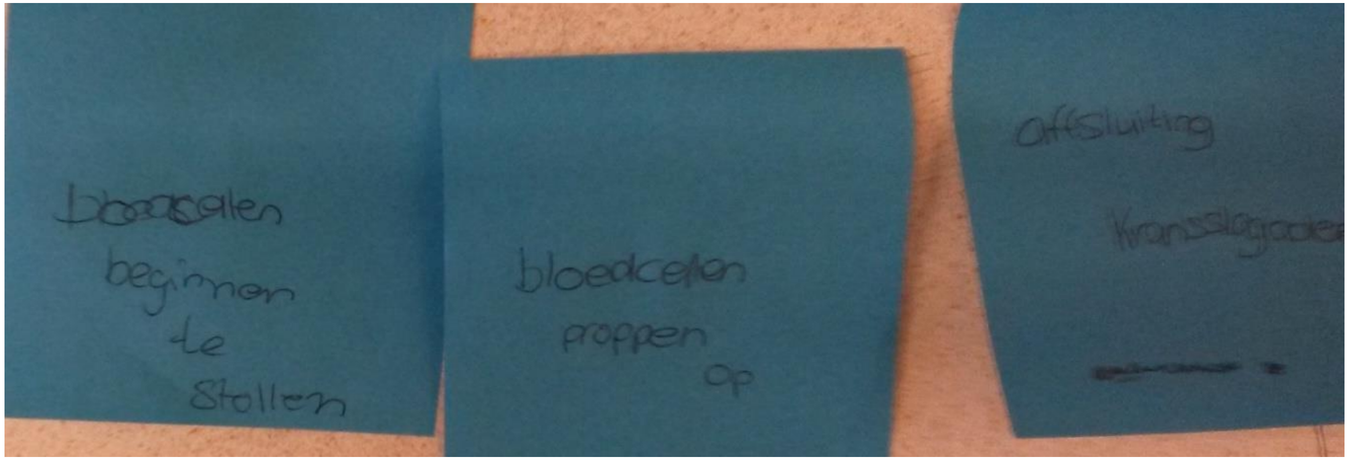

voedsel eten
met veel ver-
zadigde vetten
dit vet wordt
in je verterings-
kanaal verpakt
HdL en LDL
↑ zijn vormen
van cholestrol.

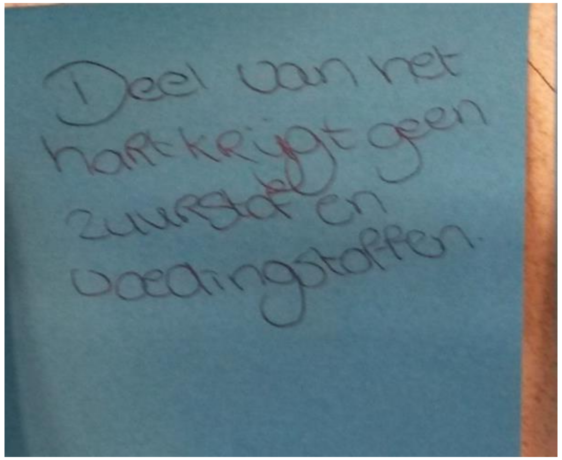

1: voedsel eten met veel verzadige vetten.
2: vet wordt wordt opgenomen in het bloed en in 2 pakketjes verpakt: HDL en LDL
3: LdL is slecht cholesterol, HDL is goed, want dat zorgt er voor dat het ~~lever~~ naar de lever gaat, daar wordt het afgebroken.
4. LDL wordt meer gemaakt. hierdoor wordt je LdL gehalte hoog en gaat LDL zich afzetten tegen de wand van bloedvaten

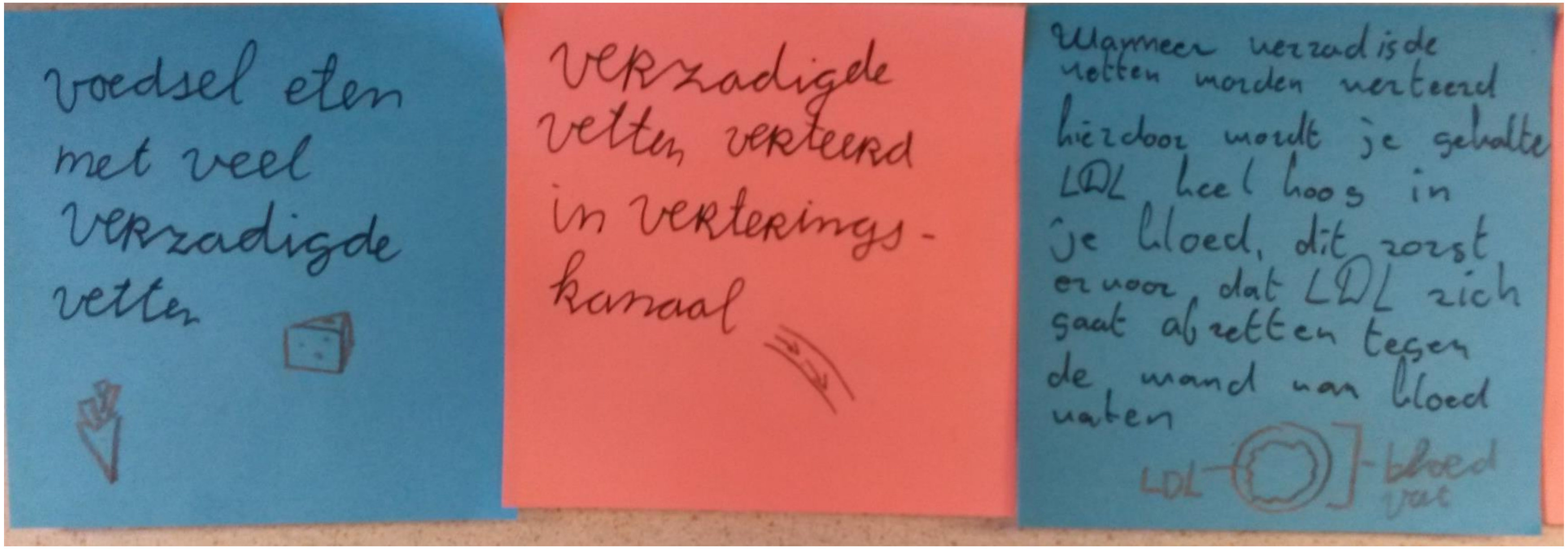

voedsel eten met veel verzadigde vetten
de kans op een hart infarct (hartaanval) wordt vergroot
er zyn meer ldl paketjes die zetten zich af tegen de wand van de bloedvaten

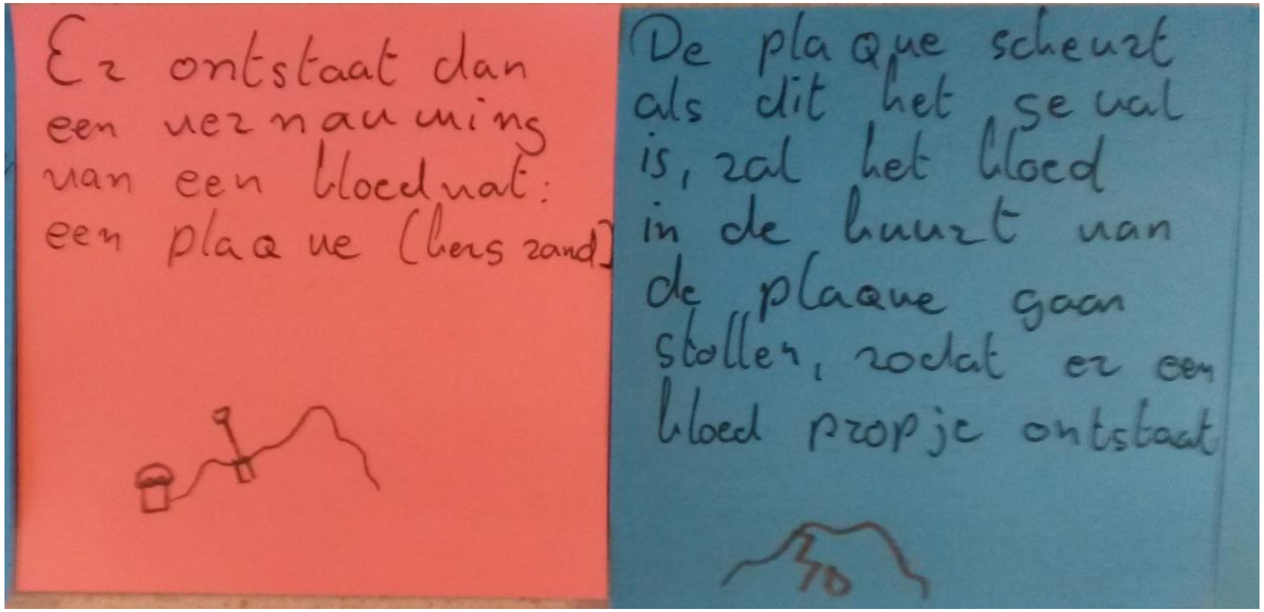

hiervorml zich een bloedprop er kunnen geen bloedcellen meer door
Afsluiting kransslagader
Deel van het hart krijgt geen zuurstof en voedingsstoffen
Hartinfarct

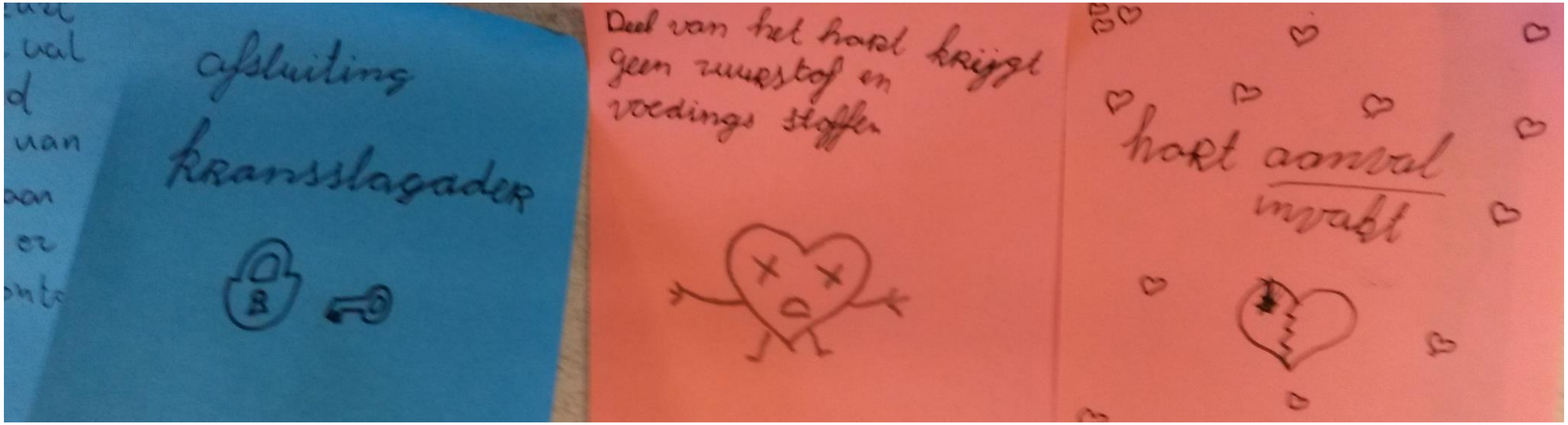

Begin
voedsel eten
met veel
verzadigde
vetten


beginnen
te
stollen
bloedcellen
proppen
op
Afsluiting
kransslagaders


Deel van het
hart krijgt geen
zuurstof en
voedingstoffen.


voedsel eten met veel verzadigde vetten
verzadigde vetten verteerd in verterings-kanaal
Wanneer verzadigde vetten worden verteerd hierdoor wordt je gehalte LDL heel hoog in je bloed, dit zorgt ervoor dat LDL zich gaat afzetten tegen de wand van bloed vaten
LDL
bloed vat


Er ontstaat dan
een vernauwing
van een bloedvat:
een plaque (bers zand]
De plaque scheurt
als dit het geval
is, zal het bloed
in de buurt van
de plaque gaan
stollen, zodat er een
bloed propje ontstaat


afsluiting
kransslagader
Deel van het hart krijgt geen zuurstof en voedings stoffen
hart aanval
infarct