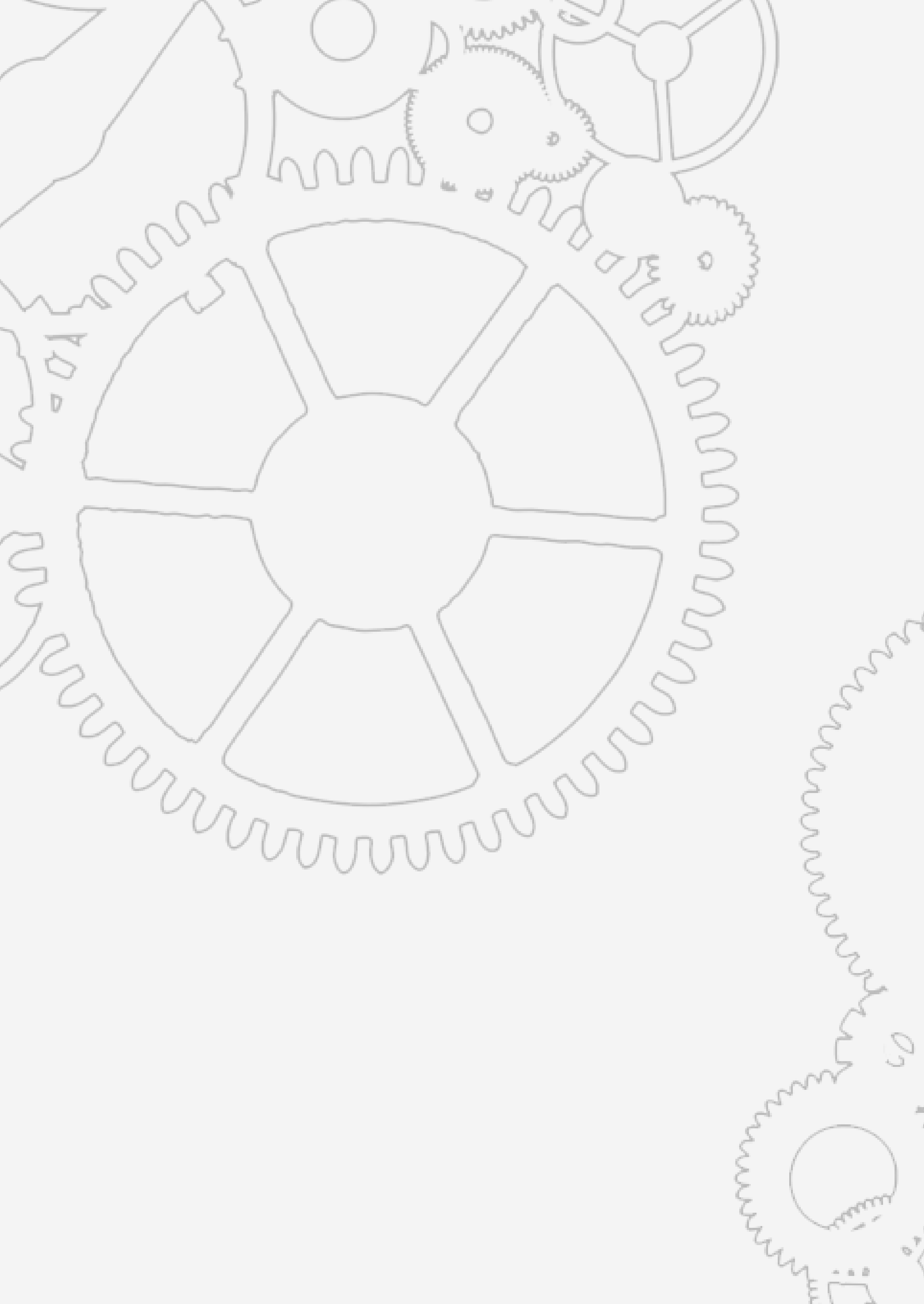

Connecting knowledge domains

An approach to concept learning in primary science and technology education

Marja-Ilona Koski

Connecting knowledge domains - An approach to concept learning in primary science and technology education
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An approach to concept learning in primary science and technology education

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In memory of my beloved grandma, Iida.

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Contents

List of Figures

List of Pictures

List of Tables

Chapter one

Science and technology education

Tech·nol·ogy is strongly present in today's society and some of the technological artifacts have become so familiar to us that we hardly recognize or even think of them as such. In the first half of the 20th century, people who used technology not only learned how to operate the technology at hand but the way technology was built was more obvious to the user, e.g. horse carriage versus modern microwave oven with digital interface. Today, all of us use technological artifacts without knowing or needing to know how these devices actually work. Modern technological devices are designed in such a way that they can be operated without knowing how the underlying technology is built.

We cannot think about our lives without any technological artifacts or inventions in it. Our needs for technology have changed as well. People have created new ways to keep in contact, transport and manufacture goods, cure diseases, and provide food to satisfy our needs. This has also given technology a power that people do not often think about. We may think that technological inventions are here only to improve the quality of our lives. Thus, we do not actively think of the possibility that technology can be misused, serve a different purpose than what we think it is made for or that it is even designed to harm us.

To understand our dependency on technology and the possible loss of control that comes with it, it is necessary for people to understand the nature of technology as well as its roots in science. It is important to know how science and technology influence our everyday life, how to use technological devices and processes appropriately and to participate in society's technological decisions (The Royal Society, 1985). Feeling comfortable with technology and the decisions we make about it is desirable. In order to recognize the aspects of technology, every individual requires certain scientific knowledge and skills. Knowledge of science is required to make informed everyday decisions, such as selecting alternative medical treatment or determining which water supply option to support with public funds (National Research Council [NRC], 2012). In other words, everyone needs to know how to make an enquiry and most importantly, to acquire an awareness of how science and technology shape our environment (Organisation for Economic Co-operation and Development [OECD], Programme for International Student Assessment [PISA], 2006[1]). If we want to raise our children to be able to function in this world, we need to provide them with the right tools to ask meaningful questions and to find information answering the questions they have.

1 The PISA 2006 report was chosen as a reference since on that year the focus was on science.

1.1. Reasons to study science and technology

Considering the above, what should we know about science and technology? Literature, such as the OECD's PISA report (2006) suggests that science and technology education in schools should enable students to become conscious citizens with a basic understanding of science. Naturally, it is not meant that someone should understand the functioning of everything and that is hardly possible either. What it means is that as a citizen some understanding of science disciplines is required to be able to participate in society and control one's own life (OECD, 2006). However, the PISA document continues that this understanding needs to happen in contexts that individuals encounter in their own lives (OECD, 2006). Thus, it is not proposed that the formulas needed by scientists in order to do their experiments, or the theories that are applied in technology have to be understood by everyone. Instead the document wants to encourage us towards acquiring basic scientific understanding that helps us to consider policy issues, such as government actions or insurance contracts, and even everyday decisions concerning risks and uncertainty (The Royal Society, 1985). By knowing the basics, citizens are aware of the relationship between science and technology and how science makes it possible for technology to be part of and influence our lives (NRC, 2012; OECD, 2006).

In our everyday life, we come across situations where at first it may not be evident that science or scientific thinking is required. Nevertheless, it is not a far-fetched thought to think that we might receive information from an unknown domain and we are asked to form an opinion about the issues concerning that domain. Let's consider animal testing as an example. In order to form an opinion about animal testing (the domain), it is valuable to be able to distinguish the opposing views, assess the information provided by all sides and judge the quality of the arguments. To do this, we need to have knowledge of how to form an opinion based on evidence and available information, we need to be able to evaluate claims made by others, and we need to tell the difference between a personal opinion and a statement based on evidence (OECD, 2006). This type of reasoning calls for scientific thinking, and lies at the core of science.

In a similar manner, arguments in favour of having basic knowledge about technology express the desire to provide tools to citizens so that they can participate in the world around them (National Academy of Engineers [NAE], 2002). People view technology as tangible artefacts, such as computers and mobile phones. However, just like science is more than formulas, technology is more than artefacts. Technological knowledge is about using that knowledge to create and operate these artefacts as well as manufacturing expertise and engineering know-how (NAE, 2002). Furthermore, the "Standards for Technological Literacy" points out that people do not only benefit from technological knowledge by being able to choose the best products to fulfil their needs, but also by making rational and reasonable decisions about how technology will be used in their own homes and within society (International Technology Education Association [ITEA], 2007)[2].

2 The "Standards for Technological Literacy" are a result of a four-year process to determine the essential core of technological knowledge and skills that ITEA wishes all primary and secondary students to acquire. These standards aim at providing an ambitious framework for guiding student learning (ITEA, 2007). Although the standards offer suggestions from the beginning of primary education to the end of secondary education, their recommendations are used in this dissertation to give an idea of what the expectations for technology education are. When referred to a specific suggestion to students at a certain grade level, the age of the students is given to clarify the level of education.

Based on the above arguments learning science and technology seems to be beneficial and therefore, it deserves a place in schools' curricula. And we should not wait until secondary or higher levels of education to start studying science and technology; it should happen as early as possible, already at the primary level. The "Benchmarks for Scientific Literacy" by the American Association for the Advancement of Science (AAAS, 2013) state that by starting this process at an early phase of education, pupils are given enough time to mature and develop abilities to handle complex explanations. At early grades, science education should focus on "*gaining experience with natural and social phenomena and on enjoying science*" (AAAS, 2013). This way, pupils still get their first experiences of scientific phenomena but have a chance to grasp concepts in a practical way.

The report on "Benchmarks for Scientific Literacy" also points out that abstraction should not be forgotten, even at early grades. Pupils should gain experience by doing science and these experiences should reflect to the basics of scientific process (AAAS, 2013). Learning concepts forms the base for technological changes. Science concepts are more stable than technological inventions; therefore, having an idea about these fundamental concepts provides the base for understanding and keeping up with the changing technology. However, technological concepts can be abstract as well, such as, concepts of system and feedback. All in all, the introduction to science and technology concepts can start through examples from everyday life and this does not mean that difficult concepts could not be tackled as well. Westbroek, Klaassen, Bulte and Pilot (2005) argue that students will be motivated by a well-defined and recognisable context and this will provide the concepts involved with a distinct function and a meaning. The approach provides a first surface to grasp on and a familiar ground to begin introducing more difficult concepts.

The above described concept-context approach is in the centre of investigation in this dissertation. As interesting as concept-context learning is, there is not much research on it yet. Therefore, at this point, only the above short description of it is given to provide an idea what the approach is about. In the later chapters, more specific references of the various concepts tackled are presented.

1.2. Reasons to combine science and technology education

According to an article in a Dutch newspaper, de Volkskrant, the House of Representatives of the Netherlands wants to have science and technology as a compulsory subject in primary education (Volkskrant, 2012). According to this initiative, the end exams, CITO toets, in the primary schools in the Netherlands focus too much on languages and arithmetic. Two members of Parliament, Anne-Wil Lucas and Tanja Jadnanansing, state that an increase of emphasis on technology in the curriculum could mean an increase of people seeking a profession in the field of technology (Nederlandse Omroep Stichting (Netherlands Broadcasting Foundation), [NOS], 2012). The members of Parliament argue that "*The earlier you start with technology the more interested children will be about technology in their lives.*" (NOS, 2012)

According to ITEA (2007) "*Young children are aware of the world in which they live, but they do not generally know how the technologies they encounter came about.* [...] *By learning how technological developments, such as buildings, highways, telephones, and artificial food have enhanced the natural world, students can begin to comprehend the vast influence of* *technology in their lives.*” Surely it is important that students know about how technological developments have enhanced our lives. However, technology education in schools should also emphasize the fact that technology is a discipline of its own and more importantly, these technological developments could not be invented without an aid from other disciplines. Technology uses scientific knowledge, and science benefits from technological inventions (OECD, 2006).

The “Standards for Technological Literacy” describe this close relation of science and technology, where science provides knowledge on the natural world (natural sciences such as physics, chemistry, earth sciences and biology) and technology offers tools to explore this natural world (ITEA, 2007). Scientists experiment in order to gain better understanding and new knowledge of the natural world, whereas technologists experiment to change the human-made world (De Vries, 2005). These types of problems cannot easily be distinguished and often require expertise from both science and technology to be solved (ITEA, 2007). The very nature of technology combines and requires knowledge from other disciplines. Consequently, teaching and learning about technology calls for coherence and co-operation with teaching and learning about other subjects (De Vries, 2005).

One way of emphasizing the importance of teaching and learning these two disciplines together is to realize that the development of a technological artifact is always motivated by a (practical) need. However, a problem cannot be solved without the appropriate knowledge. Let’s approach this through an example. Everyone who has ever visited Amsterdam or seen a picture of the city knows that the buildings next to the canals have several floors and that they are narrow. One can only imagine how narrow and steep the stairs inside are. This means that basically it is impossible to carry large objects up and down the stairs inside of these buildings. Hence, a pulley system[3] and a rope offer an enormous help.

The invention of a pulley system, and especially the use of it in Amsterdam, came from a practical need to lift and lower large objects. The idea of placing these pulley systems on to the walls was an answer to a practical problem; a need to get large things up the floors or down to the street. Another option would be to use the stairs or simply throw down the objects. Thus, before installing a pulley system several options must have been thought of and tried out. The power of this invention relies on the important realization of the relationship between load and effort (mechanics, idea of a lever). This realization led to the use of appropriate (science) knowledge to offer a (technological) solution to a practical need.

Science and technology are mutually dependent but have different purposes, as has been stated before. Where science can be expressed accurately in a form of propositions (*knowing-that*), technology also acquires knowledge in a form of skills; *knowing-how* (De Vries, 2005). Knowledge that technology employs is science combined with rules of thumb, models based on experience or simply the most convenient solution (Norström, 2011). Thus, it applies different types of knowledge and not all of them can be justified in the

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3 This invention can easily be spotted on the front side of buildings in the centre of Amsterdam. A pulley system (hijsbalk in Dutch) is “*a wheel with a groove round its rim, a sheave. A wheel or drum fixed on a shaft and turned by a belt, cable, etc.* “(Oxford English Dictionary, 1989). The system itself is not a Dutch invention; it can be found on the list of ‘simple machines’ identified by Renaissance scientists. The idea behind using a pulley system is to use a single continuous rope to transmit a tension force around a pulley to lift or move a load.

scientific sense. This creates an interesting dilemma: in technology certain ideas or models are accepted because they make describing a phenomenon easier but in science they are simply wrong, e.g. sucking vacuum[4] (Norström, 2011).

Thus, introducing and including science and technology in primary education is not as straightforward as might appear at first. This could be due to the complex relationship between the two of them. Despite all the difficulties that science and technology as a topic in a school curriculum needs to overcome, it can use its unclear position among the other subjects as an opportunity to influence the way it should be organized. But more importantly, in absence of established traditions, introducing a different approach is more likely to succeed than among old subjects, such as mathematics or history.

Hitherto, we have discussed the reasons to study science and technology together as well as the nature of scientific and technological knowledge. On one hand, these two disciplines have a close relationship and they support each other. On the other, we need to be aware of their separate, individual natures as well as the distinctive differences in the ways the knowledge is applied. In the following two sections we will first take a look at how (science and) technology or design and technology education are implemented in some countries. The author has chosen a few national curriculums or programmes as examples. After that the Dutch educational situation is explained in more detail since this research was done in the Netherlands.

1.3. The current situation of science and technology education – the international perspective

In England and Wales[5], implementation of the subject Design and Technology started in 1990 in all state schools for children age 5-16 years (Benson, 2011). The new subject had a rocky start when it was criticized to be just about general problem solving without any knowledge base. Over the years the subject has overcome many issues and developed many good methods. From September 2013 all schools are free to develop their own curriculums for Design and Technology for children aged 5-11 years (Department of Education, 2013). According to the site of Department of Education (2013), Design and Technology remains as a compulsory national curriculum subject and new statutory programmes of study will be introduced from September 2014.

Benson (2011) gives all the credit to the primary teachers that Design and Technology has become a recognized and popular subject. Although the subject has gone through many changes, much remains to be dealt with, especially in designing and developing teacher

4 Vacuum means a space in which the pressure is significantly lower than atmospheric pressure. Vacuum in itself does not suck; it appears to because of the lower pressure in the space that is (made) vacuum.

5 There is no common curriculum in the UK. England and Wales shared the same curriculum until 1995 when Wales developed its own curriculum (Benson, 2011). In Scotland technology education was included to the national education guidelines in the early 1990s, respectively (See: Dow, W. J. (2011). Technology in the Scottish primary school. In C. Benson, & J. Lunt (Eds.), *International handbook of primary technology education. Reviewing the past twenty years* (39-50). Rotterdam: Sense Publishers.).

knowledge and understanding (Benson, 2011). Primary schools still emphasize languages and mathematics above all, whilst, development of thinking skills, questioning and problem solving appear to be taught in Design and Technology (Benson, 2011).

In New Zealand, since 1999 all primary schools (pupils age 5-12 years) had to offer technology programmes as part of the core curriculum (Compton, 2011). At first, its role in the curriculum was more of a minor subject with hardly any structure between lessons (Compton, 2011). Today technology education is structured around three themes; Technological practice, Nature of technology and Technological Knowledge (Compton, 2011). Like Benson, Compton also emphasizes the important role of primary teachers if technology education ever wants to reach its potential. According to Compton (2011) the biggest challenges lie in establishing where the teachers stand as technology educators and what is needed from the teachers when it is time to move from curriculum development to curriculum implementation.

In the USA, there are initiatives towards including technology education in schools curricula (K12 system, K2-K12, children aged 7-12 years). Documents such as ITEA (2007) are created to advocate the importance of technology education. ITEA's document (2007) offers support for each grade level (K2-K12) on how to teach technology and what topics to use to engage pupils. However, the ideas do not reach as far as the actual planning of the curriculum. Planning, as well as structuring and organizing the topic are left for teachers and curriculum planners of each school and district (ITEA 2007).

1.4. The Dutch approach

In the Netherlands, science and technology is a recommended topic to teach at primary level, thus, attempts to improve primary teachers' abilities to teach it have been made. Professional development program for primary teachers was organized by VTB-Pro (Verbreding Techniek Basisonderwijs – Professionalisering, in English: Broadening Technological Education in Primary Education – Professional Development). The project ran from May 2007 until December 2010 and it was aimed at providing professional development to primary teachers in the Netherlands. The focus of the project was on helping primary teachers to implement new activities in their curriculum in the field of science and technology. The VTB-Pro project followed a theoretical framework that described what primary teachers needed to know and be able to do to implement science and technology in their classroom practice.

a) Development of knowledge of key science and technology concepts in addition to key science and technology skills,

b) Development of more favorable attitudes towards science and technology, and

c) Development of the instructional skills needed to stimulate inquiry-based learning and learning by technical design (Walma van der Molen, de Lange, & Kok, 2007).

The fundamental idea behind the program was that in order to address science and technology topics in everyday classroom situation, primary teachers have to develop their knowledge, attitudes, and inquiry skills within science and technology in an exploratory and reflective manner (Walma van der Molen et al., 2007).

The professional development activities and research in the VTB-Pro project were developed and conducted by primary teacher training institutes and universities (De Vries, Van Keulen, Peters, & Walma van der Molen, 2011). The activities and research were organized by 'Knowledge Centres' and there were five of them in the country (De Vries et al., 2011). Each of these Knowledge Centres had their own procedure of how to organize and teach in the actual training. The research presented in this dissertation started at first as collaboration with one of these Knowledge Centres. The rationale for the study was provided by Kenniscentrum Wetenschap & Techniek West (KWT-West; Expertise Centre for Science and Technology, region West)

In the following, the professional development activity provided by KWT-West is introduced. The six sessions of the training, each one afternoon long, were presented by a trainer, who was also trained by KWT-West beforehand. The number of participants, their age and in-service experience differed per group. Each of these groups met roughly once a month. The training sessions aimed at providing more knowledge of science and technology concepts as well as solutions and examples of how to deal with these topics in classrooms. The six topics covered during the sessions were:

1) Flying,
2) Survival,
3) You, your class and science,
4) Developing living quarters for sharks and corals using the expert method,
5) Your own theme (content of this session teachers can choose) and
6) Learning, living and working with water.

Each of these sessions provided the necessary background of science and technology theory, in addition to hands-on experiments. Teachers were encouraged to do homework: trying out the learned methods in their own teaching. After completing the sessions, teachers received a diploma as a conclusion of the training.

1.5. Science and technology concept learning

The previous section gave an idea of how (science and) technology education is arranged and what its position in the national curriculum of some countries is. Now that the overall picture of the field of science and technology is given, it is time to move on to the core problem of this dissertation. The following sections present the main issue that this research was interested in solving.

However, before discussing the topic of in more detail, some frequently appearing terms need to be explained first.

The term *concept* refers to subject matters relevant to a certain field, e.g. concepts in physics could be force, mass or sound, and in chemistry atomic structure and chemical reaction etc.

Concept refers to an abstraction that can either be a category name for concrete objects that have something in common, such as plants or furniture, or an abstract entity that functions in a scientific theory, such as mass and stability. Both of these introduce us a learning challenge. We cannot see or touch an 'animal' per se; we see and touch cats and dogs. The theory-related concepts, such as mass or stability are not only abstractions like an 'animal' is, but they also have no concrete objects to which they refer (see more in 1.5.1).

The in-service teacher training material of KWT-West used a definition from a Dutch dictionary and specified a concept as "*a design* or *a current formulation of a law*". To understand what a concept is, the material approached it through its opposite; a 'misconception' (examples, lists in 2.3). The training material explained that a 'misconception' appears "*when one thinks that something is correct but scientifically it is incorrect and that is a misconception.* "

Concept learning denotes learning scientific and technological concepts (or *principles)*. Science and technology concepts are often combined; e.g. a scientific principle could be the principle of Bernoulli and the relevant technological principle is the shape of the curving of a wing. Ideally, a concept is learned in a certain context and further examined and understood in other contexts (Van Oers, 1998).

Context refers to a social practice where learners carry out goal directed activities, using knowledge, symbols, language, tools and sharing meanings and values (Coenders, 2010). One way to see contexts is to take it as a concrete practical situation. Another way to view would be to see them as practices, where they are a coherent set of actions (see more in 1.5.2). The social practices are a way to deal with contexts. According to Vygotsky (1978), learners build cognitive structures through needs, purposes and actions, through their relationships with other people, and they attach meanings to these activities (Crawford, 1996). Knowledge and skills are strongly situated and humans learn through being and acting in a cultural context (Crawford, 1996). This, however, acquires learners to adapt their knowledge and skills when it is needed to use them in another social practice (Coenders, 2010). Van Oers (1998) calls this adaptation re-contextualization. This leads to learners not only understanding the concept at a higher level, but it also increases their ability to apply it in real-life situations simultaneously.

Conceptions are beliefs related to concepts. A conception related to mass is that certain objects have mass and others have no mass. '*Misconceptions*' are conceptions that do not match with current scientific insights. They mostly are developed based on practical experiences, and work properly for the limited range of those experiences (for that reason perhaps it would be better to call them 'pre-conceptions' rather than 'misconceptions'). Scientific theories, however, move away from these experiences, either by abstraction or idealization or both. This step creates a learning challenge. It requires that we can move back and forth between the concrete world of the objects we experience and the abstract world of concepts as they function in theories. By doing so, the issue of realizing the aspects of these same objects becomes more difficult and we do not recognize them in practice anymore. We see and apply science and technology concepts every day without realizing the underlying theories that make a device function or a phenomenon possible.

Thus, identifying and understanding these concepts is essential in order to understand the world. Unfortunately, several studies have shown that primary teachers and students from all the grades to university struggle with giving a scientific explanation even to a basic natural phenomenon. Primary teachers have weak conceptions about mass, density, temperature and heat (Bleicher, 2006). Also, their views on force and gravity do not correspond with the generally accepted scientific interpretations (Kruger, Summer, & Palacio, 1990). Many middle school students (Yin, Tomita, & Shavelson, 2008) and university students (Loverude, Kautz, & Heron, 2003) are not able to predict sinking and floating behavior of objects. Furthermore, future primary teachers struggle to explain concepts that are included to the content of their science lessons, such as air and air pressure (Rollnick & Rutherford, 1990).

1.5.1. Reasons to start learning science and technology concepts in primary education

These concepts are at the heart of science and the implications lie in technology and the concepts form a base for understanding abstract ideas. Applications change and develop but the underlying concepts that make them possible stay the same. In primary education, learning how bridges are built can start by experimenting with different structures. By doing that, pupils will learn what shape is the strongest and which shape is the best to build a bridge, a dam or a truck to transport liquids. In secondary school and later on in high school, learning about these similar notions starts from a much higher level of abstraction. The students are faced with different laws and principles from the beginning on and this makes identifying the basic scientific concepts with their corresponding practical applications more difficult. Thus, students can end up calculating and doing experiments without realizing why they need to know how to do what they are doing.

Piaget has stated that children only from 12 years old are able to think in terms of concepts (Woolfolk, Hughes, & Walkup, 2008). In the early years of primary education, according to Piaget, pupils are still on the concrete-operational stage (age 7 -11 years) where they are able to solve concrete, hands-on problems, in a logical fashion, though (Woolfolk et al., 2008). The problem that most learners experience when moving away from this type of learning towards concepts is how to solve a problem without using these concrete operations. Understanding concepts needs is a shift in thinking so that the focus moves from *what is* to *what might happen* (Woolfolk et al., 2008).

As difficult as abstract thinking can be, and as persistent as the assumption of children not being abstract thinkers might be in our society and education, several studies have shown that even infants have intuitive theories of the world around them (Gopnik, 2012). At the age of seven to eight, pupils will begin to understand that people use inventive thinking to adapt the natural world according to their own needs (ITEA, 2007). Piaget's theory has been critically evaluated and researchers have discovered that young children are able to form causal representations, similar to scientific theories (Gopnik, 2012; Van Oers & Poland, 2012). Van Oers and Poland (2012) continue that even though Piaget's ideas influence educational policies, schools continuously challenge young pupils with abstract activities, such as mathematical operations and grammatical parsing.

However, concept learning comes with another catch. The term *concept* refers to an abstraction that can either be a category name for concrete objects that have something in common (e.g. animal, furniture) or an abstract entity that functions in a scientific theory (e.g. mass, stability). Both pose a challenge to learning, as what we see is not an 'animal', but a cat or a dog. Children, however, seem to be able to learn the object-related abstract category at a relatively early age. But theory-related concepts, such as mass or stability, contain a double challenge. Not only are they abstractions, no less than the category of animals or furniture, but they also have no concrete objects to which they refer. We only encounter them in an indirect way. We experience the mass of an object when we try to lift it. As with the concept of ‘animal’, there is communality between objects that give us a reason to develop the concept, but with theory-related concepts it is communality in properties, and properties are already abstractions in themselves. The research, reported in this dissertation, only deals with theory-related concepts, and for that reason it can be expected that children will have learning difficulties with those. Theories are abstract representations of reality in which relations between concepts are identified; a theory in physics can be mass, force or acceleration. Sometimes these theories are called ‘principles’ (e.g., Bernoulli’s principle’, which is in fact a theory that identifies as relation between velocity and pressure - both theory-related concepts in a flowing fluid)

Although at the early age, children are proven to be abstract thinkers, Kruger et al. (1990), Loverude et al. (2003) as well as Rollnick and Rutherford (1990), to name a few, have demonstrated that later on learners have difficulties understanding concepts. Maybe the reason is that learning about science and technology concepts is not started gradually enough in our education. The level of abstraction e.g. in secondary education might be too high for the amount of exposure to science that the learners have gained until that point. Could the answer be to start learning such concepts as early as in primary education? If young children have the mental capacities to think in an abstract way, including abstract thinking to primary education makes sense. Children in primary schools are at the age when they are naturally interested and curious anyway.

This study assumes that by introducing the concepts gradually over time, the knowledge about them can be built up and the learning can begin with a lower level of abstraction. To improve concept learning in primary science and technology education we need to indentify the variables that have an influence on how concepts are approached. This study explores what the teachers’ science practices and models are, and how these practices and models need to be taken into consideration in science and technology concept learning. Furthermore, to form a complete picture of concept learning, it needs to be investigated among students and pupils as well. The level of abstraction may exceed the level of understanding of pupils, but the point of the investigation is to see the intuitive notions of science and technology concepts. It is interesting to see what their proposed explanations to a phenomenon are and how they approach science and technology problems.

At this point, it is useful to have a look at some studies interested in improving teaching and finding out factors affecting it. Vast amount of literature references can be found on how to improve teaching and what are the factors affecting teaching. In the following, instead of presenting an extensive literature review on these studies, one study per improvement or factor is chosen as an example. A large-scale study has been conducted to determine what effective teaching is (MET project, 2013). According to one of the documents from the project, effective teaching is sensitivity to students’ academic and social needs, knowledge of subject-matter content and pedagogy, and the ability to put that knowledge into practice, all to facilitate student success (MET project, 2013b). Soon after the publication of this study, it was criticized by researchers from the National Education Policy Center (NEPC, 2013). According to the review (Rothstein and Mathis, 2013) the MET-project did not solve the on-going disagreements of what makes an effective teacher and it did not help in designing real-life systems to evaluate teachers either. Furthermore, studies in topics such as how teachers’ subject knowledge and pedagogical knowledge affect their teaching have interested many researchers (e.g. Parker and Heywood, 2000). Extensive studies have been done about primary teachers' attitudes towards science and technology teaching as well (e.g. Asma, Walma van der Molen, & Van Aalderen-Smeets, 2011; Van Aalderen-Smeets, Walma van der Molen, & Asma, 2011). In addition, Rohaan, Taconis and Jochems (2012) combine different aspects and suggest that subject matter knowledge is a prerequisite for both pedagogical content knowledge and self-efficacy, and self-efficacy has further impact on teachers' attitude towards science and technology.

1.5.2. The Dutch concept-context approach in science and technology education

Concept-context learning has been considered as an interesting learning method and, therefore, it has been implemented in Dutch primary and secondary schools (Van Graft & Boersma, 2009; Eijkelhof & Krüger, 2009). A context, where learning takes place should not be seen merely as a concrete external situation, but rather as a mental framework (Van Oers, 1998). Earlier, this dissertation presented Coenders (2010) definition of contexts as social practices. Van Oers (1998) approaches contexts from a meaning-making point of view. Van Oers (1998) defines the meaning construction process as follows: "*The meaning of a sign*[6] *at one moment in time can only be established in a more or less definite way, when this process of meaning finding is supported by additional information from a surrounding field in which the meaning is functioning."* From here Van Oers (1998) derives the purpose of a context: "*The concrete or ideal field of a sign-meaning unit, that supports the specification of meanings at a given moment in time, is generally referred to as context."*

The reason why this context is so important is because it provides two processes to the learning. First of them is particularization of meanings where the cognitive process of meaning construction is constrained, and parallel meanings that do not seem to be adequate at that moment are eliminated (Van Oers, 1998). The second reason is that context prevents this particularized meaning being isolated by bringing coherence with a larger whole (Van Oers, 1998). Thus, when a pupil approaches the notion strength in a context of a meaningful activity such as building a tower from pieces of paper, this notion of strength will probably be connected to other meaningful notions, such as profiles, constructions, steady forms etc. The recognizable contexts do not only appeal to students, but they also provide 'need-to-know' basis for concepts to be learned as well as give a meaning to the concepts learned through these contexts (Bulte, Westbroek, de Jong, & Pilot, 2006).

From all the research approaches, concept-context learning in primary teachers' professional development has hardly been a topic of research[7]. Concept learning has been studied in educational settings directed at pupils. By doing more research on concept learning and by obtaining more knowledge about the topic, it can become a more visible and better-noticed

6 Here van Oers uses a notion from linguistics. He refers to the notion of meaning.

7 Stolk, Bulte, De Jong and Pilot have developed a course design and design principles for courses on teaching concepts in contexts. The research focused on professional development of secondary school chemistry teachers. See: Stolk, M., Bulte, A., Jong, O, de, & Pilot, A. (2005). Teaching concepts in contexts: Designing a chemistry teacher course in a curriculum innovation. In K. Boersma, M. Goedhart, O. de Jong, & H. Eijkelhof (Eds.), *Research and the Quality of Science Education* (169-180). Dordrecht: Springer.

part of education. Based on the above, concept-context learning and its applications in classrooms, offer an interesting field of research. There is a need for a practical approach for teachers to use concept-context learning. In the Netherlands, attempts towards introducing in-service teachers to concept-context learning through a professional training has been done e.g. in the training by KWT-West.

There are different ways of reading the term 'context'. One way is simply to take it as a concrete practical situation. In that approach a context for the concept of mass can be a person being hit by another person and then feeling like being pushed away. This is more or less the way it was taken in the 1970s when science education was made more practical by using more of these practical situations; be it that usually they were more sophisticated and related to broader social concerns. More recently, however, a different approach was suggested in which contexts are practices. This term became popular in ethics due to the work of Alisdair Macintyre, who claimed that moral behaviour can only be learnt by taking part in a social (professional) practice. A practice that is a coherent set of actions. A practice in ethics can be: the practice of health care (in which doctors participate and by doing so learn what it means to be a morally good doctor; likewise for engineers, teachers, etc.). For learning concepts in primary or secondary education, in a similar way practices can be identified, but then at the level of children's and pupils' experiences. Taking part in traffic to go from home to school daily is such a practice, as well as doing ballet in a dancing school.

It was the original intention in this research to develop lessons in which such a practice would be used to improve concept learning. Due to practical circumstances explained elsewhere (2.4, 3.4 and 6.5.1) this was not possible; hence we will not pay further attention to the little literature that exists currently on this issue. For the same reason, no further attention will be given to design as a possible practice for concept learning ('design-based learning'). Although intended originally, it appeared not to be possible to develop a full series of lessons in which a design activity would be used for concept learning.

1.6. Used methodology and outline of the research

Learning science and technology concepts and practical approaches to do that are in the centre of this dissertation. The research brought new insight into the knowledge level of teachers and students in science and technology and offers a method that helps the process of teaching and learning science and technology. The aim of the dissertation is to help teachers to use their knowledge when designing science and technology lessons.

The conclusion from the literature was that primary teachers struggle to teach science and technology and their knowledge on science and technology concepts is not on a desired level. Although professional teachers' training activities have been organized to tackle with this problem it appeared that the problem still remains. In order to identify what is hampering science and technology concept learning and how it could be helped, following questions guided the research:

- What is the level of science and technology concept knowledge of primary teachers?
- What is the nature of the 'misconceptions'?

- How can these 'misconceptions' be dealt with? How can science and technology concept learning and teaching be improved?

The research goal was twofold, first the difficulties in concept learning were determined and then a suggestion for improvement was introduced. Three main components for the research were formed based on the research questions:

1. To identify a problem (lack of proper science and technology concept knowledge),

2. To suggest a solution (the three-domain model), and

3. To test the solution (preliminary tests, exploratory phase)

The purpose of the pre-studies was to find evidence that there exist conceptual problems with primary teachers and student teachers. The purpose was not to examine the extension and severity of this problem. The fact that examples were found and that literature suggests they can be expected was sufficient motive to come up with a possible solution. This solution entails a knowledge-theoretical model that can be used in combination with different pedagogical strategies. The model was tested by proving that at least one such a strategy approved to be usable for at least one teacher. So the research aimed at proving that a phenomenon existed (the presence of 'misconceptions', the possibility of using the model), not the extent to which it occurs and for this purpose, qualitative research methods are appropriate.

The research started by examining concept learning among primary teachers already practising their profession (see list below). Based on the findings of the first study, it became relevant to explore concept learning in a similar manner among student teachers as well. These two studies provided inspiration to design a model to help concept learning. Furthermore, since this research happened in a context of education, it was natural to test the knowledge of pupils as well. A full picture of learning and teaching can be only accomplished by examining both teachers and pupils. Therefore, the third study was dedicated to pupils' concept learning. The research was concluded by testing the suggested model in classroom environments.

1) In-service teachers' concepts of air, water (such as density, force of air etc.) and systems,

2) Pre-service teachers' concepts of air and flying and

3) Pupils' (age 8-10 years) perceptions about systems.

Overall, the idea was to find an approach that changes teachers' ideas enabling them to deepen their every day science and technology practices. In secondary education, science and technology concepts have been successfully integrated though design-based approaches (Kolodner et al., 2003). This might be worth looking into in primary education as well. Kolodner's research encouraged to determine whether science and technology concepts can be learned in primary education.

The interviews and the simple assignments on paper ('pre' and 'post-tests') were used as a tool in this investigation and therefore, there is no need to use the same concept throughout the various studies. The interviews and the assignments served a purpose to establish that problems occur, and were used to suggest a general model or an approach for improving the situation. The aim of the study was not to design an inventory of 'misconceptions'.

The research was conducted by using qualitative research methods. This research method was chosen to focus on the words and expressions used in the answers. Also observations were used to support this type of research. Furthermore, the data set is rather small, thus, quantitative research methods would have been unsuitable for the purpose of the study. For all the data, a methodological triangulation was used, where ethnography and observations were applied to the research material.

Methodologically, it would have been valuable to do a design-based research study, in which a lesson (series) is developed originally as a 'prototype', tested in practice (thereby gaining insights about the properties of the intervention (the 'prototype') and its influence on the learning of concepts), and then improved, tested again etc. Due to the limited availability of teachers and schools, this was not possible. Hence, the literature about this methodological approach is not described any further here.

1.7. Outline of the dissertation

The rest of this thesis is structured as follows (see Figure 1. The arrows in the figure indicate dependencies between the chapters and studies. Dashed arrow means that the chapter/study had an influence on the other chapter/study). In Chapter 1, in-service teachers and their concepts or mental sets about science are examined. The focus is on testing in-service teachers' science and technology concepts in terms of interviews and assignments. In relation to the findings presented in Chapter 1, it could be possible that teachers start their careers with inefficient knowledge of science concepts. Therefore, Chapter 2 continues to explore this issue but this time pre-service teachers' knowledge is investigated. This chapter examines how science and technology concepts are taught to the student teachers and how they learn these concepts. To have a comprehensive view of concept learning in primary education, concept learning of young pupils is explored in Chapter 3. This chapter highlights the issues that come with introducing a concept to young pupils; namely systems and systems thinking. In Chapters 5 and 6, a possible solution on how to prepare teachers to give science and technology classes is introduced. Chapter 5 presents the theoretical background of the conceptual model, and in Chapter 6 this approach is tested and evaluated. Chapter 7 ties the thesis with a general conclusion and future recommendations.

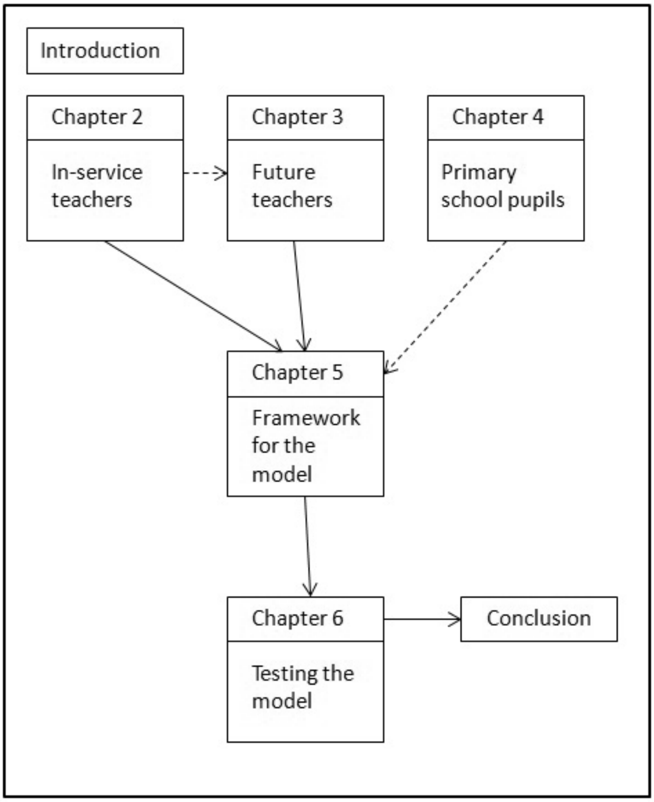


Figure 1. Outline of the dissertation.

List of publications:

Book chapter:

Koski, M-I., & Vries, M. J. de (2011). Concept learning in professional development. In M. J. de Vries, H. van Keulen, S. Peters, & J. Walma van der Molen (Eds.), P*rofessional development for primary teachers in science and technology: the Dutch VTB-pro project in an international perspective* (167-180). Rotterdam: Sense Publishers.

Journal articles:

Koski, M-I., Klapwijk, R., & Vries, M. J. de (2011). Connecting domains in concept-context learning: a model to analyse education situations. *Design and Technology Education: an International Journal, 16*, 50-61.

Koski, M-I., & Vries, M. J. de (2013). An exploratory study on how primary pupils approach systems. *International Journal of Technology and Design Education, 23,* 835-848.

Koski, M-I., & Vries, M. J. de (accepted). An aid for teachers to teach science and technology concepts - two case studies to test the three-domain model. *International Journal of Technology and Design Education*.

Koski, M-I., & Vries, M. J. de (submitted). Being a teacher – thinking like a student? *European Journal of Teacher Education*.

Conference proceedings:

Koski, M-I., & Vries, M. J. de (2011). What makes teaching science and technology difficult? Investigating pre-servive teachers' knowledge level. In Stables,K., Benson, C., and Vries, M. de (Eds.), Proceedings of PATT-25 Conference, *Perspectives on Learning in Design &Technology Education* (236-242). London: Golsmiths Univesity of London.

Koski, M-I., & Vries, M. J. de (2012). Primary pupils' thoughts about systems. An exploratory study. In Ginner, T., Hallström, J., and Hulten, M. (Eds.), Proceedings of PATT-26 Conference, *Technology Education in the 21st Century* (253-261). Linköping: LiU Tryck.

Chapter two

2. In-service teachers' pre-concepts in science[8]

2.1. Introduction

Pro·fes·sion·al development of teachers is at the centre of this dissertation. The idea is to get an impression of primary teachers' knowledge of science and technology concepts, to identify the problems in teachers' concept learning and to suggest a solution. This chapter presents the first of the three qualitative studies done to reach the above described goal.

The chapter investigates primary teachers' knowledge of science concepts related to air and water. To assess the effects of professional development programs, it is necessary to know the ideas with which the teachers enter the program. Here the in-service teachers' science and technology concepts are examined in terms of 'simple' assignments on paper. Investigating such pre-concepts is not a new research field and for that reason the study can use the existing research methods (e.g. Bleicher, 2006). New in this study, compared to the earlier studies, is that it is done for primary school teachers. Existing studies make it possible to compare results on other target groups such as primary school pupils and secondary school teachers.

First in section 2.2 an overview of the other studies into concept learning is presented. In section 2.3 the research questions for this study as well as the methodology are derived. Section 2.4 presents the collection of data, and in section 2.5 the data are analyzed. In this section the primary teachers' pre-concepts and the first impressions of the effects that the professional development activities had and can have on the teachers are presented. In section 2.6 the discussion based on the findings is given. The conclusion is presented in section 2.7.

8 Based on: Koski, M-I., & Vries, M. J. de (2011). Concept learning in professional development. In M. J. de Vries, H. van Keulen, S. Peters, & J. Walma van der Molen (Eds.), *Professional Development for Primary Teachers in Science and Technology: the Dutch VTB-Pro Project in an International* Perspective (167-180). Rotterdam: Sense Publishers.

2.2. Study in to concept learning

In order to combine science and technology education as it was described in Chapter 1, we need to include activities that change primary teachers' ideas and enable them to deepen their own science (and technology) practices. Unfortunately, only a minority of primary teachers have a fairly good knowledge of science content; in addition, they do not have the confidence to teach science (Appleton 2003). In some countries, the choice of not teaching this topic is no longer available and teachers cannot avoid teaching science and technology anymore; even if their confidence about it is low (Harlen & Holroyd 1997). Science and technology teaching is faced with demands that are based on the nascent science and technology education research as well as on the involvement of technology in our lives. Teachers need to adjust their teaching to correspond to this. According to e.g. Taylor, Jones, Broadwell and Oppewal (2008) more experience in performing science research, as well as developing primary students' own critical thinking skills should be practiced in schools.

Previous research includes investigations regarding the student confusion over the concepts being taught and the failure to recognize contradicting answers (Loverude et al. 2003). Kruger et al. (1990) found out that both teachers and primary school students have the same wrong interpretations of certain science concepts when they tested primary teachers' knowledge about force, gravity and friction. As well as the teachers and the students, the teacher trainees hold the same wrong ideas about air and air pressure (Rollnick & Rutherford 1990). It appears that primary students and teachers share the same wrong concepts about science and technology. Furthermore, She (2002) discovered while testing the conceptual change of air pressure and buoyancy that students are more reluctant towards the conceptual change if the underlying concepts are not comprehensible.

This chapter examines primary in-service teachers and their underlying concepts or mental sets in science (and technology). More precisely, the chapter is interested in how teacher's practices and models need to be taken into account for an effective change to happen. Therefore, before developing classroom activities, the possible factors stopping the transform process in teachers need to be examined. This chapter aims at making the difficulties in science and technology concepts visible and establishing what types of problems in teacher's knowledge level this brings out.

2.3. Description of the chosen research method

Lewis (1999) states that understanding the conceptions and misconceptions is an important prerequisite for better teaching and improved student learning. This same idea was applied to the testing conducted at the professional training for teacher. The study aims at finding the nature of 'misconceptions' in the teachers' knowledge of the physics that is related to the training activities they went through. The aim is not to develop a complete inventory of 'misconceptions'. If there is evidence that teachers hold certain types of 'misconceptions', this will give a reason to find a way for improving their conceptions in physics. By gaining a better perception of the teachers' knowledge, the professional training can be helped to meet the needs of the teachers. This can also help to adjust the training and develop it further. Thus, the question that this study wants to answer is:

> Are there examples of 'misconceptions' related to the VTB-Pro training activities provided by the KWT-West that need to be addressed in order to ensure that

teachers will deal with concepts in their lessons properly?

The concepts that were tested had to be covered in the KWT-West's in-service teacher training material (for the list of topics, see 1.4). The topics 'Water' (floating and sinking) and 'Air' (air and flying) were chosen because in and thorough them the concept learning was explicitly introduced to the in-service teachers.

The data were collected by means of assignments. Examples from the book of Unesco Source Book for Science were used as a source of inspiration. In this book possible practical approaches for physics concepts are introduced to teachers to use in their classrooms. A deeper understanding of what to look for came from the article of "Force Concept Inventory" by Hestenes, Wells, and Swackhamer (1992). They have created questions for students in order to test what the common sense beliefs and 'misconceptions' of the physical world are. Based on these questions and their explanations it became comprehensible to what extent it is possible to find results with this method and what can be investigated.

During the construction phase of the assignments, each individual question was discussed and evaluated together with Prof. Marc de Vries and Dr. Remke Klapwijk. Before handing in the questions to the teachers, the questions were evaluated and answered by an outsider. This test was done in order to test if the concepts are correctly addressed and inquired with the questions.

The design of each individual question is either based on the author's idea or it relies on the article "Diagnosing and Dealing with Student Misconceptions: Floating and Sinking" written by Yin et al. (2008). Even though this article is designed to test student misconceptions, it does not only provide ideas but usable tests to see the 'misconceptions' of the teachers in the professional training as well.

The final versions of the assignments included seven questions each. In both assignments the first question was more of an introductory question to the topic. The assignment for topic Air tested the following concepts (see also Appendix A).

1) What is air? (general ideas about air)
2) Mass of air. (Is air something?)
3) Force of air. (Can air move things?)
4) Density[9]. (Can something be lighter than air?)
5) Relationship between air pressure and altitudes.(The higher air rises, the lower the air pressure)
6) Relation between air pressure and temperature. ((The lower the pressure is, the colder the air) and

9 The density or volumetric mass density, of a substance is its mass per unit volume. The author acknowledges that weight of a gas should include investigation of its volume as well. Because of the training and the material used, 'lighter than air' is used in an 'inaccurate' way in this dissertation.

7) Bernoulli's principle[10] (How according to Bernoulli's principle planes can fly?)

Questions 1, 3 and 4 were open questions where teachers were invited to write in their own words what they thought the correct answer would be. Questions 2, 5-7 were multiple choice questions where four options were given, one being the correct answer.

Similarly, the assignment for a topic related to Water tested the following concepts and 'misconceptions' of floating and sinking (see also Appendix B).

1) What is water? (general ideas about water)
2) Archimedean principle (Do all big and heavy objects sink?)
3) Archimedean principle (What happens when weight is loaded off into the water from an object floating in water?)
4) 'Misconception': Shape determines whether an object sinks or floats. (Does shape influence whether an object will sink or float?)
5) Density. (Why an ice cube floats in one liquid but sinks in another?)
6) 'Misconception': Hollow objects float. (Will hollow objects float)
7) Systems thinking. (How does a coffee machine work?)

In here the questions 1-3, 5 and 7 were open questions. Questions 4 and 6 had two options, one true and the other one false.

This study was qualitative in its nature. It followed the description of qualitative study by Henn, Weinstein and Foard (2008) by being a small-scale but detailed and rather intensive study. The chosen method was used to construct an understanding of teachers' pre-concepts. Although, numbers and amounts were used to present the results, the emphasis was on the language used in the answers. The analysis was mostly based on the answers given in the assignments but in some cases the observations made during the professional training were reported as well. These observations were used to explain something in the results that could not be understood by simply viewing the answers.

2.4. Data collection

The data were collected during the spring of 2010, in teachers' professional training

10 The wings of an airplane are designed in such a way that the upper side of the wing is curved and the bottom side is almost straight. "When a stream of air flows past an airfoil (this case wing of an airplane), there are local changes in flow speed round the airfoil and consequently changes in static pressure, in accordance with Bernoulli's principle. The distribution of pressure determines the lift, pitching moment and form drag of the airfoil, and the position of its centre of pressure." Clancy, L.J., Aerodynamics, Section 5.5. Lift is a reaction force— According to Newton's laws of motion, wings create a lift because they deflect the air flow downwards.

sessions organized by KWT- West. The sessions, in which the author could be present, were dependent on the schedule of each trainer. These trainers were appointed to the author. The amount of in-service teachers per training session varied and could not be controlled by the author (further explanation later in this sub-section). Some of the answers had to be excluded from the final data set because of a trainer's wish not to have outsiders observing the training session. Therefore, the data were collected only from the training sessions of one of the trainers.

To execute the study without further delays, the author decided a minimum requirement for the answers to be part of the final data set. Thus, each assignment had to be accompanied at least by an observation made during the training. This decision shifted the focus of the study. Instead of comparing teachers' pre- and post-lesson answers, the analysis concentrated on the *pre*-concepts that the teachers possess before they participate in professional development activities.

The trainer was a teacher at a University of Applied Sciences and her background was in Arts. The training sessions took place at her school or at the school of the in-service teachers. Usually, the location was one of the teaching rooms at a school or a common room, such as central hall etc. None of the locations was designed for teaching neither science nor technology, though. The training sessions were held after the regular school hours, and each session lasted about three hours including a small break in between.

The trainer had a set of training kits that included all the necessary tools and materials for the teachers to do the practical experiments during these training sessions. It was possible to transport the kits by car, thus, the trainer could take them with her when she taught outside of her own school. Unfortunately, the training was more focused on implementation of all the experiments designed for the materials in the kit than explaining why the experiments were done. Teachers in this training did the experiments alone without feedback. They were not challenged to explain why the experiment did not succeed or to explain why it worked.

In the end the analyzed data consist of answers given by 24 teachers and observations made during the training sessions. To the assignment about concepts in 'Air', 11 pre-lesson answers were given. Similarly, 13 pre-lesson answers were given to the concepts related to 'Water'. It was designed that this group will answer the post-lesson assignments as well. However, due to scheduling conflict only two teachers from the group were present on the day of testing. Section 2.5.6 analyses their answers in detail and this is used as a validation for the results.

All of the teachers who answered to the 'Air' assignments were female and their ages were between 30 and 64 years. From the 13 teachers (age between 25 and 58 years) that answered to the 'Water' assignments, three were male. Teaching experience of all the teachers varied from three to 40 years of experience. Their experience in teaching technology varied as well. Some of the teachers had taught technology their entire career (40 years out of 40 or 10 years out of 10), some of them had a long career as a teacher but very little experience in technology education, and some of them were relatively young as teachers but possessed already few years of experience in teaching technology.

Most of the teachers participated in the training because they wanted to learn new ideas or refresh or gain more knowledge. Some of them were there out of their own interest; some of them were signed up by their principal. But in general, they wanted to learn more about how to teach technology and if possible, how to teach science.

2.5. In-service teachers’ pre-concepts

Here the data analysis[11] is divided in to two parts based on the findings. The analysis of the pre-lesson assignments revealed three topics that need to be further examined in order to overcome problems in teacher training:

1) Universal use of science theories,
2) Relationship of these theories and practice, and
3) Learning how to freeze the thinking process.

First these topics are discussed and after that an analysis on teachers’ abilities of system thinking is presented. This second part introduces a more detailed analysis of the answers of teachers that gave answers to both pre- and post-training assignments. The second part serves as reliability check to the findings introduced in the first part of the analysis, as described earlier.

On average, teachers replied to all of the questions. However, the analysis revealed similar findings throughout the questions. Therefore, the author has decided not to present all of the questions in this analysis. An example of each phenomenon is chosen instead of presenting several similar examples of the same concern.

2.5.1. Ideas about water and air

Before focusing on those three topics that need more attention in teachers’ concept learning, let’s view teachers’ written answers to the question on what is water. Majority of them answered with terms such as

> “*Water is liquid*”, “*It is necessary for life*”, “*We use it daily*” and “*We use it in everywhere*”.

The concept of air was described in terms such as following

> “*Not visible*” or “*Not touchable*”, “*You can feel it in the wind*” and “*You cannot live without it*”.

These types of answers indicate practical, representational, down to earth qualities of these science concepts. It appears that these teachers have the same tendency as students to link their concepts of matter to tangible properties (Davis, Ginns, & McRobbie, 2002). Therefore, an approach to the topics, which supports the learning style of the teachers’, is to give examples that are sensible and closely related to everyday life.

11 The answers given by the teachers are translated from Dutch and checked together with Prof. Marc de Vries and Dr. Remke Klapwijk.

2.5.2. Universality of theories

Teachers' thoughts and ideas about air and air pressure have been asked earlier in a study on African teacher trainees (Rollnick & Rutherford 1990). In the study of Rollnick and Rutherford (1990) the questions were concerned with concepts such as, existence of air, does it occupy space or exert pressure. In this study, the in-service teachers' knowledge of the concept mass of air was examined by asking them to decide which glass bottle weighs more the one filled with air or the other one made a vacuum (Appendix A, question 2). In the answers more than half of the teachers stated that adding or removing air from the bottle does not change the weight. A vacuum bottle weighs more according to two of the teachers. However, two of the teachers replied correctly that the bottle with air weighs more. Considering that more than half of the teachers gave a reply where air has no weight, it seems that air is considered as something without the quality of mass.

The next question (concept: force of air) examined the perceptions of the concept of air further. The teachers were asked to determine whether it is possible to pump air into a swim ring that has five books on top of it (Appendix A, question 3). Eight teachers thought it was possible (one answer was just positive without explanation). Examples of the written answers are given below.

> "*Yes, the air goes into the ring and everything is lifted*",
>
> "*Yes, the ring becomes firm*",
>
> "*Yes, the ring expands and the books will be lifted*",
>
> "*The books will rise if you put enough air in. The mass of the air is more than the* [mass] *books*" and
>
> "*This can be. The air pressure in the ring is on the given moment greater than the weight of the books and that's why the books can be lifted".*

Contrary to the previous question, here teachers could imagine the conditions or they might have even experienced a similar situation. It appears that this triggered them to reason that air has mass and that air can change conditions (e.g. air fills something). Three teachers explained the situation with changed condition of the swim ring (ring becomes firm or expands). Four teachers explained the phenomenon by using terms such as *the increase of mass* or *the weight of the air*. In these explanations the mass of air or the weight was considered, correctly, to be greater than the mass of the books.

However, three teachers doubted the method because of the alignment problem of the books. Below their written answers:

> "*It depends on how and where the books rest*",
>
> "*It is possible but if the books are not well arranged, they will fall*" and
>
> "*One book can well be lifted by one ring. But a stack of 5 books is heavy. If you pump the ring that has 5 books on top of it, you will succeed only partially. The pile will slide off and fall over. After that you*
> *can continue pumping the ring*".

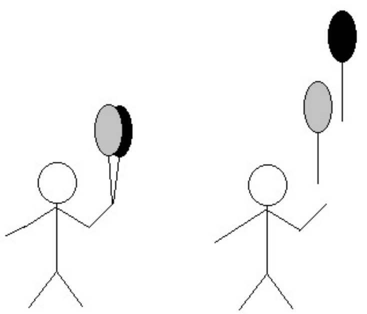
Findings of these two questions contradict with Rollnick and Rutherford's (1990) study on explanations of air and its effects on other objects. In that study, the answers stated that air is invisible and has power. Here it is not clear how the teachers understand air; it seems to be something without a mass but it can exercise force. Even if the concept of air is familiar and the theories concerning it are known, the knowledge does not seem to have a universal usage. Theory might be well learned but how to apply it and recognize the situation where the knowledge could be used seems to be difficult. When teachers could visualize the situation, the results improved. This, however, does not necessarily ensure that the concept is understood. A situation in which the teachers had to rely on theory and only imagine the situation, such as the question about the mass of air, demonstrated a difficulty of applying the knowledge, whereas the next, a more concrete situation resulted in better explanations and shows understanding.

When analyzed what is triggering the scientific thinking or more precisely what is stopping it, it seems that the knowledge level may not be solid or stable enough. The assumption made among children that learned theories lack universality (Yin et al. 2008) can be detected in the teachers' answers as well. Therefore, the promotion of universal use of knowledge by presenting several examples, even the ones that do not work, could help teachers to create clearer ideas about the concepts. However, despite the method, a trainer should pay more attention to checking whether a concept is learned and even more importantly, how it is learned.

2.5.3. Relationship between theory and practice

The training introduced practices, which were meant to elicit a more scientist-like behaviour in the teachers. The trainer encouraged her in-service teachers by saying "*What we do in here is as much science as anything*". Ideally teachers have this type of approach towards science and address science as the scientists do. The approach to science and doing science should be open and personal where both theory and practice support one another.

Figure 2. Two differently behaving balloons.



The concept of density was generally well understood in the pre-lesson assignments (Appendix A, question 4). It was the most popular answer to the question of what makes the other balloon rise and the other one stay put (Figure 2). The concept was described with following sentences:

> "*The red balloon is filled with heavier gas than the yellow. The gas in the red balloon is also heavier than air around it*",
>
> "*In the yellow balloon there is gas that is lighter than air around it. In the red balloon the gas is not lighter because the red balloon does not sink down or rise upwards*",
>
> "*If there is helium in, is this gas lighter than air and is pushed upwards*" and
>
> "*In the yellow there is helium and in the red one there is air that is blown. Helium is lighter than air*".

However, the written answers also included replies such as

> "*There is probably gas in it*",
>
> "*Due to the gas the balloon rises*" or
>
> "*The other balloon is filled with gas*"

When analyzing these answers, it seems that also other characteristics of air have a tendency to be incorrectly understood. In this case, most of the answers were correct but for the research and development purposes the incorrect ones are more interesting at this moment. The incorrect replies give an impression that air is not seen as a gas and it does not have anything to do with the fact that a balloon rises or stays put. Contrary to this, it has been reported that air consists of a variety of gases (Rollnick & Rutherford 1990). It seems that air is perceived as something of a "zero state" and not as a mix of gases. Balloons that rise are once from fairs. There balloons are filled with gas and that makes them rise. Hence, a more suitable knowledge for this situation was the one from a real-life experience instead of a science based explanation. Using real-life experiences is not a wrong approach per se; they just need to be correct.

To the question about the concept of Bernoulli's principle [12] (for explanation, see the list of concepts in section 2.3) almost half of the teachers thought that because there is a longer distance for the air to travel on top of the wing, the air floats slower and due to this high pressure is created. According to the training material the reason why lift is created is because air moves faster on top of the wing creating a lower pressure to the top part than below the wing. Lift is about higher pressure but it should be below the wing.

The above answers, especially the ones about the density, show a problem between an

12 The training material explained concept of lift based on Bernoulli's principle, although incorrect (Newton's laws of motion are needed). However, since Newton's laws were not included, the teachers cannot be expected to know them either. Hence, the results have to be interpreted as if Bernoulli's principle (on the level it was taught) would explain the whole phenomenon of lift.

abstract theory and using the theory in practice. The theory stays as a theory, learned for a reason but the practice, the context where this theory could be used, is another world where different theories are applied. A certain investigation process is missing, which would make the relationship between theories and practice more visible and present. It is important that the concepts are connected to a recognizable context (Bulte et al., 2006) because theory and practice are strongly situated, and this, acquires learners to adapt their knowledge and skills, especially when used in another context (Coenders, 2010). These recognizable contexts would not only provide and give a meaning to the concepts learned but also they appeal to learners (Bulte et al., 2006).

Based on the answers to the pre-lesson assignments, the connection between difficult theories should be made more tangible. The theories need to be integrated with practice. They should not exist only to present scientific concepts and then a different knowledge of the same concept is used to apply in practice. Use of meaningful, recognizable contexts would prevent theory from being isolated and it would link it to a larger whole (Van Oers, 1998). Most likely it is not enough to explain a concept once but it needs to be repeated. Therefore, a trainer needs to come back to it and to make a connection to another practice as well.

2.5.4. Learning how to freeze the thinking process

Let's move on to the pre-lesson questions concerning the concepts related to 'Water'. The teachers used up- and downwards forces (concept: Archimedean principle) correctly to explain the floating of a big iron boat (Appendix B, question 2). Answers included written replies such as the following

> "*It has to do with the up- and downwards forces*",
>
> "*Due to the heaviness of the boat, it has to do with the upwards pressure of the water*" and
>
> "*Because the upwards pressure of water is bigger than the downwards force of air*".

The answers presented above are partially unclear and vague but on a whole it seems that the underlying theory is understood. Answers in which just a term is mentioned or a bigger confusion is observable were given as well. The following written answers give an example.

> "*Buoyancy of the water*",
>
> "*Surface tension, buoyancy*",
>
> "*The form of the boat determines that it floats. The hollow shape determines*"
>
> "*Iron doesn't absorb water*".

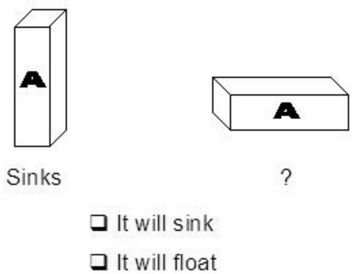
Mentioning just a term is a sign of knowledge gap but declaring surface tension as a reason for a boat to float, describes confusion. The answers showed similar confusion as among students, when they have stated that the amount of surface contact with water determines sinking or floating (She, 2002). Here the form and shape were causes for the boat to stay on the surface. It appears that the teachers replied with known terms and not so much with their knowledge. The answers showed a lack of full understanding of the concept and its use in practice. Replies such as the above indicate that it is important to make time for teachers to reflect on the experiences they gain during the experiments.

Similarly to Yin et al. (2008) teachers were asked to compare the same block placed differently in water (Figure 3). The question stated that a block is placed into water vertically and it would sink. The second time it was put in horizontally and teachers needed to decide whether it would sink or float (Appendix B, question 4).

In the study of Yin et al. (2008) children answered that the horizontal block floats. Here half of the teachers stated correctly that on the second time, the block would sink as well. However, the other half, six teachers, answered that it would float. Thus, similar results to the study of Yin et al. (2008) can be detected among the in-service teachers as well.

Type of answers such as in the above two, suggest that teachers have learned to use correct terms without thinking what that term means. For this reason, it is important that the theories are connected to their tangible, observable properties and not introduced only as concepts. The provided training material attempts to improve this by instructing teachers to answer to a question "What happens?" Based on the results, however, it seems that this is not enough. Teachers also need to learn to answer to a question "Why does this happen?" Learning to stop and re-evaluate the situation helps to avoid simplest mistakes and encourages questioning the thinking patterns. Additionally, this acquires extra attention from the trainer. Teachers cannot merely observe the experiments or quickly run them through. Instead, they need to be actively involved during the experiment and encouraged to think themselves and make assumptions.

Figure 3. Block placed into water in two different ways (Yin et al. 2008).



2.5.5. Thinking in systems

A question about systems and system thinking was given to 13 teachers. There are many definitions, all of them more or less the same, to what systems thinking is. Booth Sweeney and Sterman (2007), e.g. define systems thinking as a group of three abilities; understanding the parts of a system, the connections among these parts and seeing a system as a whole.

This part of the study aims at finding out notions of system thinking that in-service teachers have. It is not expected that teachers are capable to reason back and forth between objects and the concept of systems, as would be the case in real system thinking. Only 'seedlings' of system thinking that could occur when teachers are asked to talk about objects for which system thinking can contribute usefully are explored. So the research question for this part is:

> Can elements of systems thinking be found in the thinking of primary teachers that participated in the KWT-West training activities?

An example of a system was presented with a picture of a coffee machine accompanied by a description from its user manual. All of the answers presented in this sub-section are taken from the written answers. The question was divided into three sub-questions (Appendix B, question 7). The first one asked which elements in the coffee machine have an effect on each other. Most of the answers were such as the following ones

> "*On/off –button -> (red) lamp on*",
>
> "*Filter -> coffee quality*" or
>
> "*Aroma control button -> stronger or milder coffee*".

Even though it was given in the question that the elements *have an effect* on each other, most of the teachers replied in a straightforward way; one component influences another and the state of the later one changes.

One of the teachers replied after listing components "*… coffee jug and drop lock in the filter holder*". When a coffee jug is placed under the filter it releases the drop lock allowing the coffee to drip into the jug. If the jug is not under the filter, the lock is 'active' and if the machine is on, only the filter is being filled. Even though this answer does not explain the relationship between these two components, the relationship between the two components is obvious to everyone who has used a coffee machine. The answer could be interpreted in a way that the dependency and interaction between the two components and a certain "backwards" type of thinking, which is common in systems thinking, is present.

The second question asked about what types of influences can come from outside of the coffee machine and can these have an effect on the system. The word influence was mostly understood as a synonym to malfunction. Only one teacher replied that an influence could be human action: "*put on* (machine) *and put coffee* [in]". Even though the influence was clearly stated in this answer, the effect on the system is missing.

> "*Power supply -> no power -> no coffee*" and
>
> "*Disturbance in electricity -> machine stops*".

In the above answers, the parts are working together and from a (negative) influence the system stops functioning normally. These answers state the source of an influence, the influence itself and the effect.

The following answers describe the effect but the source of the influence or the type of influence is missing.

"*Jug out of its place -> overflow*" or

"*No coffee powder -> only warm water*".

In the end, most of the answers described states of the machine or the end product.

"*Filter isn't placed correctly*", "*No water in the water tank*" or

"*Coffee type -> taste*", "*Water -> no coffee*".

These answers are malfunctioning states of the machine or end results produced by a falsely functioning system. They do not state the influence to the system or the effect on the system itself.

The answers to the third part of this question described the possible situations or changes occurring within the system in the following way:

"*Water to steam*",

"*Cold plate to warm plate*" and

"*Solid (coffee powder) to liquid (ready coffee)*".

The first two answers are not explaining the situational changes within the system but the last one is a result of process in the coffee machine. Eight teachers explain the following situation in a more or less detailed way:

"*From water to coffee*" or

"*Water becomes warm, sets off, and mixes itself with the coffee powder -> water gets colour and taste*" or even more detailed

"*Water becomes warm -> evaporates and rises up through the pipe, cools there and condensates, runs through the filter and mixes there with the coffee powder and falls to jug. Jug is warmed by the plate under it*".

In systems thinking, elements are interdependent and cycles appear within procedures. Most of these answers present a linear way of thinking about processes and systems. Overall structures, patterns and cycles are difficult to find in the answers. Even though there are signs of systems thinking, the idea of a network or a complex whole is missing. In most of the cases independent parts are described.

We will continue exploring the concept of systems and systems thinking in Chapter 4.

2.5.6. Concept understanding before and after the training

In this section, written answers to three questions to both pre- and post-lesson assignments from two teachers are presented.

The training material explains the principle of Archimedes roughly as follows:

> "*The upward buoyant force exerted on a body immersed in a fluid is equal to the weight of the fluid that the body displaces".*

In this question, the teachers are given a scenario where a child plays in a bath tub with a toy boat that is filled with toy blocks. Teachers were asked to tell what happens to the boat and to the water level when the child starts unloading the blocks into the water.

> Teacher A: "*Boat rises in the water*" and "*Water level will be lower*"
>
> Teacher B: "*The boat sinks (depending on the buoyancy and weight) further to the bottom or sinks*" and "*The water will rise as much as the content of the blocks*" then the teacher continued by commenting on the water level of the bath tub "*Depending on the content and how far the bath is filled with water, it (water) will flood or not*".

Teacher A started correctly explaining the situation. The reasoning became incorrect in the second sentence. However, this could be related to the rising of the boat, meaning that the water level is compared to the position of the boat. In the case of the other teacher, a clear false concept of the Archimedean principle is seen in the part where the teacher claimed that the water level will rise as much as the content of the blocks.

In the post-lesson assignments the teachers were asked to simply explain the basic idea of Archimedean principle. This revealed the difficulty of the theory. Teacher A replied with one word "*gravity*" while the other teacher replied by writing: "*Apple falls from the tree and this action provides the needed reaction*". Findings of these two questions support earlier stated difficulty of explaining a theory and how more descriptive questions trigger teachers to explore more options to answer the question.

The concept of density was asked by giving a picture of two glasses, filled half way with liquid (Figure 4). In the other one an ice cube is floating and in the other one it is at the bottom. Both ice cubes are identical in terms of weight and size. Teachers were asked to explain why a situation like this can occur.

> Teacher A: "*In the other cube there is more air?? That's why it floats*"
>
> Teacher B: "*The liquid is a different type (e.g. salt or soap)"*

The post-lesson assignment had the same question only without the picture. However, this time it was given that the other glass contains water and the other one alcohol (two liquids with different density). The two teachers replied the following:

> Teacher A: "*The density of alcohol is bigger than water's*"
>
> Teacher B: "*It is a matter of another*

density, where the molecules in the ice are closer to each other than in the water around them.
In alcohol this is not the case"

The answer of teacher A in the pre-lesson assignment shows a false concept in which the objects that are filled with air float. This similar result was reported among students by Yin et al. (2008). The second time the term density appeared but it was wrongly understood. The density of water is greater than the density of an ice cube or alcohol. Contrary to this in Loverude et al. (2003) students mostly stated correctly that the behaviour of a floating object is due to lower density than the density of water.

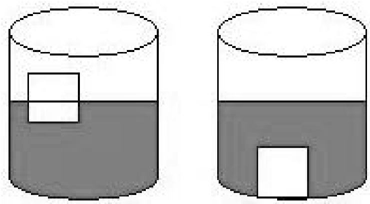
The first answer of teacher B is in a sense correct (liquids are indeed different and that's why the scenario is like presented), but when compared to the second one, it shows the same problem than what the teacher A has. Density as a term is used but it is understood the other way around.

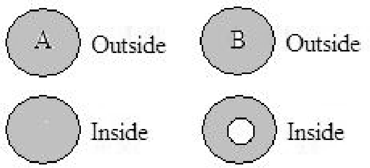
After the training, density as a term was known but how it works was vaguely understood. It seems that greater density of a liquid makes an object sink. Teacher A stated this clearly but also teacher B ended up with the same conclusion. The first sentence of teacher B was incorrect but the second one, if you assume that the density of an ice cube is all the time the same, made sense. But now the densities are the other way around than what they should be. Again according to this, alcohol has the greatest density, then ice cube and then water. In this case the teachers were able to explain the theory, which implies that the theory was learned. However, the theory was wrongly understood and this could be due to the lack of right explanation and an improper connection to an experiment.

Yet another question about floating and sinking was asked with the help of a figure. This question was not altered between the assignments. The balls in the picture look the same from the outside; they have the same mass and volume (Figure 5). However, ball B is hollow from the inside and the balls are made from different materials. It is given that ball A will sink. The question was: will ball B float or sink? Teacher A replied in both assignments incorrectly that it will float. In the pre-lesson assignment teacher B replied: "*It depends on the material they are made of. If made from same,*

Figure 4. Two ice cubes in different liquid.

Figure 5. Comparison of two balls (Yin et al. 2008).





it will sink". In the post-lesson assignment teacher B stated correctly that it will sink as well.

The given answers support the findings of the previous question. Here, the same false concept of hollow objects floating appears, similar to results of Yin et al. (2008). In the pre-lesson assignment teacher B related sinking and floating to the material choices, which is incorrect (also because it is given in the question).

2.6. Discussion

Based on the analysis, the method used in the professional training needs to pay more attention to how teachers understand the concepts being taught. Vosniadou and Ioannides (1998) reported similar results and concluded that students in their study were not given enough time to understand the concepts. Although not having enough time to learn the wanted concepts is clearly one of the sources of the problem, lack of time does not explain all of the issues. Since the time for the teachers' professional training was limited to six sessions, it seems pointless to discuss about adding more time to the training. Instead it is more fruitful to focus on the connections between concept and context, or more precisely, on the lack of it.

Bencze's (2001) finding that the offered method of providing practical approaches to learning a concept does not promote students to construct their own knowledge supports the fact that the chosen practical approach needs to be carefully considered. Based on the findings of this study, it appears that the practical approach plays a more central role. The practical, hands-on examples may not be enough for teachers to connect the theory from the training material to the experiment shown and practiced during the training. The theory needs to be embedded into a context that is recognizable and meaningful to the teachers at that point of the learning.

Teachers have knowledge that covers the surface level of the theories and this may hamper them in fully exploring the possibilities in practice. Fear of failure might be one of the reasons why the teachers will not try out the learned methods. The values that scientists think are significant when doing science are relatively far out of reach for the teachers at the moment. However, this could be overcome by dedicating enough time to the theory and practice individually as well as together, and repeating this process several times. In this way, the training could show the teachers how science works but also give them enough time and opportunities to do science themselves. The professional training should be about learning how to ask questions in a more scientific way. It is vital to learn to ask "what happens" but also "why it happens".

The reason why offered knowledge stays on a superficial level could be due to the type of training provided by the trainer. The training did not challenge the current knowledge of the concepts enough and the teachers left the training without changing their knowledge of theories. She (2002) argues that students are not willing to change their ideas if the underlying theories are not properly understood. It is reasonable not to expect anything else from the primary teachers either. It is challenging to change a working concept, even if it is a false one in scientific terms, to another concept that has not convinced the teacher yet. Thus, research on how training teaches the concepts, is essential. Shifting the focus more towards describing the concepts than providing the material to work with, might enable the desired outcome. Showing as many experiments as possible has a good reason underneath it. However, running through them too quickly has almost the same effect as not showing them at all.

Hand and Tragust (1998) observed that students often leave the classroom without changing their 'misconcepts'. Teachers share these same false concepts as their students and changing these concepts seems to be a complex process. This change appears to be relatively difficult to reach with the way the training was organized. It is in fact reasonable not to expect big changes with a training that has just six sessions, especially if teachers after more than a year long in-service training still hold on to their old concepts (Jarvis & Pell, 2004). Even university students may fall into using similar false concepts but they have years to change their ideas and they are constantly exposed to the scientifically accepted point of view.

Teachers have their ideas and theories how things work and these ideas and theories do not conflict enough with the scientific theories to make the wanted change (Hand & Treagust, 1988). These theories could be relatively easily overcome if a new, better working theory was made available to replace them (Hestenes et al. 1992), but this does not happen with the training at the moment. It is logical to hang on to these false concepts because they work in everyday-life. In everyday-life situations it is acceptable to have more than one theory per concept and they can conflict with each other (Posner, Strike, Hewson, & Gertzog , 1982). This is only unacceptable in science.

Thus, a more in-depth teaching method is needed. Teachers need to learn in a way that the concepts are connected to their everyday-life, to a meaningful context. These concepts should also be connected to a practical application or a product in which teachers can see the concept being used and favourably, can touch it as well. This way the concept is joined together with understandable artifacts from teachers' own life. The idea on joining these three components together is further examined in Chapters 5 and 6.

2.7. Conclusion and implications for the professional development

The first issue that the VTB-Pro training activities need to address is that the primary teachers' have various pre-concepts and these concepts do not match with the ones that are used and taught in science and technology.

The second issue is that in order to guarantee a proper delivery of science and technology concepts in the classrooms, the VTB-Pro trainers need to address the issue of teachers' various pre-concepts and where to pay ample amount of attention and how to improve knowledge delivery. The method, used at the moment, does not provide enough support for teachers to connect a concept to its practical application. Because what was learned in the training was not consolidated, there is no guarantee that the concepts were learned or even applied in practice.

As a general suggestion, it is argued that instead of putting the emphasis on providing material to work with in the classroom, the focus should be on describing the concepts through a social context that is familiar to teachers. Furthermore, the theory that is needed in order to understand the concept requires a link to a concrete object in which the concept is being applied. With this approach good understanding can emerge within the teachers.

These results have an implication to practice. Often these concepts have a value in dealing with practical situations, and therefore, the term 'misconceptions' in situations like these is misleading. The pre-concepts help us deal with practical situations in a fairly successful way. It is not uncommon to hear phrases such as 'heat rises' or 'wood floats and metal sinks'. These 'facts', however, remain limited to that particular situation and do not provide a broader view on reality by connecting different situations and phenomena. For that reason, learning of the 'proper' concepts, that is, the way they are used and taught in 'real' science and technology does have a value.

The chapter underlines the fact that this is not an easy matter in a case of primary school teachers. Their lack of background in science and technology is not easily compensated by a limited number of activities directed at learning certain scientific and technological concepts. Although this study is too small to provide a sound basis for general conclusions, it does suggest that the activities may not make a great impact on the way the teachers conceptualized certain phenomena. In the professional training (VTB-Pro project) time for activities focused on concept learning was limited. As a consequence, expectations for change must be modest. The study has shown that substantially more is needed in order to realize real changes in teachers' thinking.

Research and attention on how training teaches these concepts is essential. However, before recommending a solution to teachers' concept learning, more information about teachers' concept knowledge is called for. To form a better view on teachers' concept knowledge, it is worthwhile to see how these concepts are introduced to them in their pre-service education. Therefore, in the next chapter, concept learning is further investigated among pre-service teachers. The idea is to see how science and technology concepts are learned in a teacher's earlier education. Maybe some of the issues that the professional training faces can be traced back to the teachers' earlier knowledge of science concepts. Thus, in Chapter 3 a study of student teachers' pre- and post knowledge of science and technology concepts is presented.

Chapter three

3. Concept learning in pre-service training[13]

3.1. Introduction

Pri·ma·ry in-service teachers' pre-concepts showed that the teachers struggle with the understanding of theories, and that they do not connect these theories with a practical approach suitable for teaching that theory. These issues, to which a relatively short professional training cannot offer a solution, suggest that maybe their views on teaching and learning science and technology are a result of their pre-service education. Therefore, this chapter examines the same science and technology concepts of students studying to become primary teachers. The purpose was to analyze how science concepts, namely air and flying, were taught to the student teachers and how they are learned these concepts. The idea was to see how the way these concepts are taught and learned in their education could affect primary student teachers' abilities to adapt and include science and technology in to their teaching.

This study was conducted in a similar way to the earlier study. First, in section 3.2 a literature study into teacher education is provided. Then, the participants and the research method are shortly described in sections 3.3 and 3.4. The data collection is presented in section 3.5 and data analysis in section 3.6. In this section, the knowledge of science and technology concepts before and after a science class is examined. In section 3.7 the effects of the training in the light of how these activities support their science and technology teaching are discussed. Section 3.8 provides the conclusion of this study.

3.2. Study into science teaching

Literature offers various proposals to teacher education on how to improve science education. For decades there has been a debate as to what to include in teacher training, what skills and ideas the training should offer, and how (future) teachers actually form their 'teaching knowledge'. One of the most radical arguments is made by Butts and Raun (1969),

13 Based on: Koski, M-I., & Vries, M. J. de. Being a teacher – thinking like a student? *European Journal of Teacher Education* (submitted).

where they indicate that those teachers with few or no courses in science have the most positive attitude towards it. According to researchers these teachers are more positive towards the impact of science and they also see science existing outside the study books (Butts & Raun, 1969). The attitude towards science is essential, but according to Felder, Woods, Stice and Rugarcia (2000) some science principles cannot be taught through practice alone and even teachers need to learn these principles from somewhere. Furthermore, it should be kept in mind that the teachers in the study of Felder et al. are likely to be experienced ones and therefore, can use learned teaching practices in order to teach any subject whether they have sufficient knowledge of that subject or not (Sanders, Borko, & Lockard, 1993). However, to develop science teaching and more importantly to provide student teachers with adequate skills, it is not enough to rely on teacher's attitude or experience. Earlier teachers could have taught science just by knowing how to teach but this may not be enough anymore to fulfil the requirements of what students need to be taught today (Niess, 2005).

To increase the quality of science teaching in primary science teacher programs, Ucar and Sanalan (2011) argue that by paying more attention to the science method courses, instead of the science content courses, an improvement could be accomplished. Furthermore, these method courses, regardless of the amount of science content courses taken, should provide experiences of positive, meaningful and engaging science methods to the student teachers (Hechter, 2011). In any case, a successful learning process should be an interaction between the existing knowledge base and the new knowledge (Anderson & Ortony, 1975).

Stevens and Wenner (1996) believe that the problem is in the absence of collaboration between the required subjects, e.g. mathematics and how to teach mathematics. Since neither the increase of subject-centred courses nor methods courses has brought the wanted improvement, they propose that more effort should be put into collaboration between science departments and departments of education (Stevens & Wenner, 1996). However, independent to what approach is chosen, the teacher training should balance between the development of teacher's subject matter knowledge (SMK), as well as the pedagogical content knowledge (PCK) (Rohaan, 2009).

In the early years of teacher's teaching career, an absence of general pedagogical knowledge constrains science teaching (Mulholland & Wallace, 2005). However, later on when the base of teaching knowledge grows, teaching science is enriched and broadened as well, but this does not necessarily guarantee an increase in the science knowledge (Mulholland & Wallace, 2005). This knowledge of knowing what and how to teach (also craft knowledge) is an integration of teachers' PCK combined with learned teaching practices (Van Driel, Verloop, & De Vos, 1998).

Nevertheless, there are other demands for teacher education as well. The content should not only focus on PCK and SMK. The teacher education should teach student teachers to reflect on the problems that arise in the classroom and provide chances to practice solving these problems (Carter, 1990). Student teachers need to invent their own explanations, and their teachers can help in this by providing richer images of science and challenging ideas with alternatives (Abell & Smith, 1994). Student teachers' conceptual understanding can be enhanced by applying instructional approaches, where alternative explanations and sufficient repetition are provided (Abell & Smith, 1994; Bleicher, 2006). But this, yet again, should not come in an expense of other areas that a teacher needs to master, like classroom management (Carter, 1990).

For both students and teachers, the emphasis in learning science should be on experiencing the nature of science without forgetting the facts and principles (McComas, 1998). There is a necessity for methods and resources of teaching that can facilitate understanding of science in an enjoyable way (Negrete & Lartigue, 2004). As important as it is to engage students into science, some theories cannot be explained through practice (Felder et al., 2000), some of them simply need to be lectured.

3.3. Participants and the education institutes

To investigate the development of primary teachers' science knowledge, a study was carried out among students from two higher vocational education institutes for teacher education (from here on institutes) located in the Netherlands. The students will become primary teachers, graduating with a Bachelor degree. The study took place during the spring months in 2011.

The study in these institutes provides students with theoretical education and practical professional qualifications required for higher-level occupations. The student teachers participate in lectures, seminars and projects. In addition to this, the student teachers are required to complete a work placement (internship) on their third year. This naturally happens in schools where they also do a research project for their final thesis.

When the assignments were given to the student teachers they were on their third year of study and the tests were done during their compulsory course on science and technology. The idea behind this course is to introduce basic science and technology concepts to the future primary teachers and show them how to conduct basic classroom experiments in a way that is interesting to their pupils. Thus, the idea was not to learn only the theories but to be able to execute experiments that describe the concepts and engage pupils to experiment by themselves.

In total, 56 student teachers took part in the study, 50 of them were female and six of them male. The participants were 18 to 25-year-olds and most of them had little or no education in science before, except for the few with an interest in science.

In both institutes the lesson took place in one of the science classrooms. The rooms had all the necessary equipment and materials needed to demonstrate the experiments. In the institute A the student teachers sat in rows, sitting two to four students next to each other. The desk of the trainer was in front of the classroom, where all the experiments were demonstrated. In the institute B the desks were arranged in a shape of an U and the experiments happened on a desk placed in the middle of the U.

In the institute A, the lesson took place later in the afternoon and it was the last lesson of the day for the student teachers. In the institute B, the science lesson was one of the first lessons of the day.

Besides some assistance from the student teachers during the experiments in the institute A, the lessons in both institutes were teacher-led. The lessons had a relaxed atmosphere and it was easy for the student teachers to ask questions at any moment. In the institute B the trainer encouraged the students to discuss in groups their ideas of what the right answer might be. Nevertheless, all the different elements of the lesson; experiments, group or pair discussions, independent work etc., happened on the instruction of the trainer.

In general, it appeared that the trainers and the student teachers had a good relationship with each other. Both of the trainers were well prepared to give the lesson, they had all the necessary material ready and the lesson ran smoothly. In the institute B the student teachers were more passive students than in the other institute. Maybe the student teachers in the institute A merely appeared to be livelier than the other group because of the time of the day. However, the two groups showed no big differences between them; most likely because of the teacher-led teaching approach of the lessons.

3.4. Research method

Because this study was inspired by the study presented in Chapter 2, it continued the research along the same lines. It applied similar research method (assignments and observations) in order to see how these concepts are learned in student teacher training (see paragraph 2.3 for detailed description of the research set-up). Both of the teacher trainers had participated in the KWT-West's professional development training, thus, the two topics were familiar to them as well. Data comparison between these two studies was also straightforward because of the similarities of the assignments.

The study aims at finding evidence of the nature of 'misconceptions' in the student teachers' knowledge of the physics that is taught to them. Yet again, the aim is not to develop a complete inventory of 'misconceptions' that the student teachers might have. If there is evidence that student teachers hold certain types of 'misconceptions', this will give a reason to find a way of improving their conceptions in physics. So the question that this study wants to answer is:

> What is the nature of 'misconceptions' related to the student teachers' science and technology education that need to be addressed in order to ensure that student teachers will deal with the concepts in their future lessons properly?

Firstly, a coordinator from KWT-West provided a list of ten teacher trainers that would participate on the research. In the end two of them showed interesting participating. Secondly, a meeting with both of the trainers was organized individually. The study differed from the previous one (in Chapter 2) in this part because the trainers needed to be convinced to participate in the study. After this, the topic of the lesson as well as the content and purpose of the assignments was discussed with the trainers. This was done in order to include the concepts asked in the assignment in to the lesson. A schedule for the pre- and post-lesson assignments was also set during this meeting.

One of the teachers wanted to extend the co-operation and asked if the author could teach the basics of how to do research to the student teachers. Later that spring the student teachers had to do a research report of their own. So after both assignments, the author went back to the institute and explained her 'research steps' until that point and afterwards. Also preliminary results of the assignments were shown to the student teachers. This was done to demonstrate to them that research is usually done anonymously and that their individual answers could not be traced back.

As stated before the same questions designed for the previous study were used. The description of the tool can be found in section 2.3. Slight moderations to the questions were made from the request of the teacher trainers, e.g. this time Harry Potter books were placed on top of the swim ring instead of Dostoyevsky's books.

3.5. Data collection

The data included a pre-lesson assignment, observations and video recordings during their science and technology lesson, and a post-lesson assignment answered about a week from the lesson. Some of the student teachers were not present in both of the assignments. To compare the knowledge level before and after, those student teachers that returned both of the assignments are included to the final data set. Thus, data include answers from 35 student teachers, 32 female and three male.

The other observed the lessons in order to get a full picture of what was happening in the lesson. The video recordings are a proof of that. The recordings are also used to validate what the trainer and the students said and to be able to make the transcripts.

From these 35 student teachers, 24 were from the institute A and 11 from the institute B (Table 1).The order of the questions was altered between the two assignments but in this chapter the questions are presented in a same order to avoid confusion. The reason for alteration was to avoid memorization as much as possible. Like in the previous chapter, this study was qualitative by its nature as well although tables are used to present numeric information. The tables are included so that the reader can see the amount of answers given per question. This is, however, background information and the focus of this study is on the language used.

The first question (Q1) asked about the characteristics of air. After that, questions about weight (Q2) and force of air (Q3) were inquired. Furthermore, the concept of density (Q4) and the principle of Bernoulli (Q5) were asked plus the questions about air pressure as well as temperature and pressure. For a detailed description of the concepts asked, see section 2.3, Appendix A and Appendix B.

As can be seen in Table 1, the post-lesson assignment had two different first questions. In the institute A the

Table 1. Answers given to pre- and post-assignments in both of the institutes.

	PRE-LESSON					POST-LESSON					
	Q1	Q2	Q3	Q4	Q5	Q1a	Q1b	Q2	Q3	Q4	Q5
INSTITUTE A	24	24	24	23	24	24	-	24	24	10	24
INSTITUTE B	11	11	11	11	11	-	11	11	11	2	4
# answers per question	35	35	35	34	35	24	11	35	35	12	28

post-lesson assignment question (Q1a) was the same as in the pre-lesson assignment (Q1). Since the pre-and post lesson assignments from the institute A were much alike to the ones given by the in-service teachers in the first study, the author decided to alter the question. In the institute B the question (Q1b) required student teachers to tell whether they think they are ready to teach science and technology after the lesson.

In general, the student teacher answered all the questions in the pre-lesson phase. In the post-lesson phase, question 4 appears to be the most difficult one, and question 5 in Institute B was left blank by more than half of the student teachers.

In both institutes, the purpose of the three-hour lesson was to give an idea about inquiry-based learning and to show how to use it in the classroom. Both teacher trainers emphasized the importance of teaching science (and technology) through investigation. The teacher trainer from the institute A (from here on "Adam") gave several examples that were equivalent to the questions. His examples included demonstrations about the principle of Bernoulli[14] as well as the weight and force of air. Overall, the lesson included practical experiments that the student teachers could use in their future classrooms.

In the institute B, the teacher trainer (from here on "Bonnie") also gave examples on how to approach science with pupils, but her emphasis was more on the methods of teaching science, and how to think and deal with question from pupils. However, she included discussions about the concept of density and a demonstration of Bernoulli's principle in to her lesson.

3.6. Analysis

This section presents analysis[15] of five of the seven questions made. A similar selection of questions was done as previously. Equivalent phenomena were detected throughout the answers and therefore, the questions that elaborate a certain phenomenon in concept learning the best are included. The two first questions presented in this section are questions Q1 and Q1a; the characteristics of air and Q1b; student teachers' readiness to teach science. After them, the same order of questions as they appeared in the assignment is followed.

Examples are mostly taken from written answers from the student teachers. However, transcripts from the lesson are used to explain the data. Unless mentioned otherwise, the answers are those give in the assignments.

3.6.1. What is air?

The first question in the pre-lesson assignment asked student teachers to describe the characteristics of air. Typically, they replied with a list of different features, such as

14 Student teacher training material and trainer used the same "false" concept of how lift is created as in the in-service teacher training.

15 The answers given by the student teachers are translated from Dutch and checked together with Prof. Marc de Vries and Dr. Remke Klapwijk.

> "*Oxygen*", "*different matters/particles/gases*", "*nitrogen*" and "CO_2"

References to quality such as transparent or invisible were popular as well. Also terms, such as following, were used

> "*Air pressure*",
>
> "D*ifferent pressures move*" and
>
> "*Expands in heat and shrinks in cold*".

In addition, they mentioned e.g. that air has an influence on the weather etc. Although most of the student teachers seemed to use the correct properties, the explanation revealed that maybe the idea behind the property is not understood: "*Low pressure (you don't notice that there is pressure)*". The study of Rollnick and Rutherford (1990) does not classify properties of air to this extent but similarly their study reports student teachers using characteristics such as air being invisible or transparent. Their study does not mention the particle nature of air or any of the other terms reported here. Different results cannot be explained based on the findings in the data.

During the lesson in the institute A, Adam emphasized the following concept of air several times:

> *"One of the science principles that you need to know is that air is not nothing. If you move your hand in the air, you feel the air. You feel it in the wind that the air is not nothing."*

In the 24 post-lesson answers, a strong influence of Adam's example could be observed. Phrase "*air is not nothing*" was mentioned in several of the answers, and an increase of terms move and movement as a property of air was detected in the answers as well.

Although the student teachers still preferred to answer with a list of particles, the demonstrations surfaced terms, like mass and weight. Pressure, invisible, transparent and influence on temperature were also popular descriptions. Furthermore, unclear answers such as weather, H_2O, and removal of oxygen were given as well.

3.6.2. Readiness to teach science

Question 1b asked from the student teachers their thoughts on whether or not they feel ready to give a lesson on concepts related air. Table 2 presents types of answers received.

Most of the student teachers believed that their skills are not on an adequate level to teach a lesson. Two of the students were positive about their skills, like students in Southerland, Sowell and Enderle (2011). One student teacher appeared to be confident about teaching a lesson because she knows more than the pupils and she masters the art of teaching. This contradicts the findings of Mulholland and Wallace (2005), where they state that in the early years of a teaching career the lack of general pedagogical knowledge limits science teaching.

Let's move on to the questions that tested the actual science concept knowledge.

3.6.3. Mass of air

The second question asked the student teachers to compare the weight of two bottles (See Appendix A, Question 2). The idea behind this question was to see the student teachers' knowledge on the concept mass of air.

In Table 3 the results are presented. In the pre-lesson assignment, 12 student teachers selected the correct answer, however, option A was the most popular. This indicates that air was considered to be something, but without weight. Rollnick and Rutherford (1990) report partially similar results, where before any instruction to the topic, the student teachers understood well the existence of air (here: option A).

In the institute A, Adam approached the concept with a following example (see below the transcript from the video recordings). Adam brought in front of the student teachers a scale, a bicycle pump and an empty plastic bottle (a valve from a bicycle attached to a cork cap) and asked one of the students to come and be an assistant.

Table 2. The answers received to a question about student teachers' readiness to teach science.

Types of answers	#
No, because I don't have good enough background knowledge yet.	5
Yes, I can, but I have to get deeper knowledge to be able to give a good lesson.	2
No, I would have to really go deeper into the topic but I find this really not interesting topic and therefore I remember so little.	2
I think yes. Children know now so little over air. I have enough knowledge about the basic principles to explain and answer to the questions. I can also do nice examples to explain the explanation.	1
No.	1

Table 3. Answers per option in pre- and post-lesson assignments in both of the institutes.

	PRE-LESSON				POST-LESSON			
	A	B	C	D	A	B	C	D
INSTITUTE A	9	2	10	3	0	0	24	0
INSTITUTE B	6	3	2	0	0	3	6	2
# answers per question	15	5	12	3	0	3	30	2

Adam: "*Now we are going to weigh the bottle.* Could my assistant now say how heavy the bottle with the cork and air inside it is?"

Student A: "*One and fifty.*"

Adam: "*One and fifty...what? Grams.*"

…

Student A starts to pump air in to the bottle…

Adam: "*Stop it now. Feel now the bottle* (hands the bottle to Student B)."

Student tries to press the bottle.

Adam: "*It is hard now. There is extra air in it. Will you pump it one more time? ...Yes! Now the moment of surprise. How heavy is it now?*"

He puts the bottle again on the scale.

Student A: (laughing)" *Two and fifty!*"

Adam: "*TWO AND FIFTY GRAMS! YES! So, how much air have we pumped in it?*"

Many students together: "*One gram.*"

Adam: "*One gram.*"

It appears that this was a successful demonstration because in the post-lesson assignments all the student teachers from the institute A replied correctly (see Table 3). However, it should be noted that since the post-lesson assignments were given relatively soon after the lesson, this short exposure to the concept might have led to a casual memorization (Vosniadou & Ioannides, 1998).

In the institute B, Bonnie did not present an example that would directly correspond to this question. Yet, an increase in the amount of correct answers can be observed. The student teachers that replied correctly in the pre-lesson assignment chose the same correct answer again. Two student teachers, who chose option A in the pre-lesson assignment, selected in the post-lesson assignment option C instead. Furthermore, the data showed that some of the student teachers chose the same or different wrong option in the post-lesson assignment. It appears that discussions over air and its properties had an influence on the thinking of some of the students. On the other hand, when no directly matching example was presented, false concepts continued to exist as well.

3.6.4. Force of air

The next question inquired whether it is possible to lift five Harry Potter books by blowing air into a swim ring underneath them. The question asked to state whether the student teachers agreed or disagreed with the technique, and to give an explanation why. The student teachers from the institute A gave nine yes- and 11 no-answers, four of the students wrote that both options are possible. Examples of the typical reasons are presented in Table 4 below.

In the institute A, the concept was demonstrated in the following way:

Adam places a crate on a student teacher's desk.

Adam: *"Here, I have a plastic bag. And I place it under (crate) and when I blow, what will happen?"*

Students silently: *"Nothing."*

Adam: *"What will happen? Tell me what?"*

Students silently: *"Nothing."*

Adam blows air into the bag and the crate goes up.

One student teacher claps her hands happily together and says to a friend: *"I told you."*

Adam: *"It is heavy, right?"*

Student B: *"Yes, but it is lighter than five Harry Potter books."*

Adam: *"Is this lighter than seven Harry Potter books?* (Adam grabs the crate)"

Students: *"Yes."*

Table 4. Different reasons why the technique will or will not work and the amount of answers given per option.

PRE-LESSON			POST-LESSON		
Answer	Example explanation	#	Answer	Example explanation	#
YES	*After a while the books will rise since the pressure is high/ Air is strong enough to lift the books*	9	YES	*Air has enough pressure to lift the books*	12
NO	*The books are too heavy*	5		*The ring lifts the books with the force of the air*	3
	Only the parts without books get filled	3		*Air has a mass which has to go somewhere. Therefore the air presses against the books pushing*	1
	Because the ring is round and the books will fall off	2		*It is possible to lift the books*	8
	The books close the opening	1			
YES/NO		4			

Student B: *"That's what I think."*

Adam takes the crate away and brings another one full of books.

Adam: "*Do you think this is as heavy as Harry Potter books."*

Student B: "*Yes."*

Adam: "*So this is as heavy as the Harry Potter books."*

Adam places the same bag under the approved crate and starts to blow. The crate goes up.

Adam: "*You didn't see it now, right?"*

Student B: "*Yes, I saw it."*

Adam: "Yes? Ok. So it happens easily, because it (air) has mass [sic].

In the post-lesson assignment, the question was asked in the same manner. All 24 of the student teachers agreed that the books can be lifted. In the answers, 12 student teachers stated that the increase of pressure inside the ring made it possible; three of them thought that air is strong or powerful enough to lift an object. Additionally, eight student teachers replied that the technique works but did not give a reason why.

In Table 5 the pre- and post-lesson answers to the same question from the institute B are presented.

As can be seen from the table, the explanations were rather similar to the ones from the institute A. In overall, the answers were less coherent, though. Since this concept was not demonstrated in the institute

Table 5. Different reasons why the technique will or will not work and the amount of answers given per option.

PRE-LESSON			POST-LESSON		
Answer	Example explanation	#	Answer	Example explanation	#
YES	*It slowly pushes the books up because the air need to go there*	3	YES	*When the air pressure becomes too big it pushes the books up*	3
		2		*If the ring is blown up very hard, the books can be lifted, but not completely because the books are heavier than air*	2
	Only the parts without books get filled	1			1
NO	*For a little while it is practical but then they fall off*	3	NO	*The air can't lift the books because the books are heavier*	3
	Books are heavier	1		*They will fall off*	1
	Gravity pulls the books down	1		*They fall due to the gravity*	1

B, the pre- and post-lesson answers do not differ much between the two assignments. Interestingly, two student teachers replied that "*the force you use to blow air into the ring*" is a factor that determines whether the books will rise or not (post-lesson column, second yes-answer).

3.6.5. 'Lighter than air'

The fourth question tested the concept of density. The student teachers were asked to give a reason to a situation such as one in Figure 6.

The most popular answers were

> "*There is (probably) helium in the other balloon*" or
>
> "*Warm air makes the balloon rise and cold air makes it sink/stay put*".

From all the student teachers, two students from the institute B gave the right answer with both; the explanation for the situation and why the situation occurs. They stated that "*the other balloon has helium in it, which is lighter than air*". Obviously, other answers included the explanation and the reasoning parts as well, but they were wrong from the beginning. The rest of the explanations included answers such as

> "*Different gasses in- and outside the balloons",*
>
> *" In the other one there is more air and the colour, lighter colour goes first up than the darker colour*",
>
> "*The balloon goes up because of the wind. The wind has more power than the balloon to stay put*" or
>
> "*The amount of air inside the balloon determines the rising/sinking*".

In both institutes the teacher trainers addressed this concept. However, the focus was on how warm and cold air 'behaves'. In the institute B the topic was approached as follows (see transcript from the video recordings below).

> Bonnie: "*Warm air is lighter than cold air.*
> *Is it true or not true?"*
>
> Student: "*True."*
>
> Bonnie: "*That is true and why is that true?"*
>
> Student: "*... the air rises..."*
>
> Bonnie: "*But is it then lighter if it rises?...What happens when you put on the heating?"*
>
> Random discussion. It seems that Bonnie didn't get the right answer.
>
> Bonnie: "*Let's park this idea for a while. What is the difference in weight?*

Think what happens when you warm up the air?"

Student: "*Molecules*"

Bonnie: "*Molecules or such ...what happens to the molecules?"*

Student: "*The molecules start to move faster and the distance becomes bigger."*

Bonnie: "*That's it! It is about the density. Air is not nothing...what is there in air*?*"*

Students give lists of particles.

Bonnie: "*There is helium in the balloon. Balloon filled with helium is lighter than air."*

Student: "*That is correct."*

Bonnie: "*....Helium is a very light gas.*"

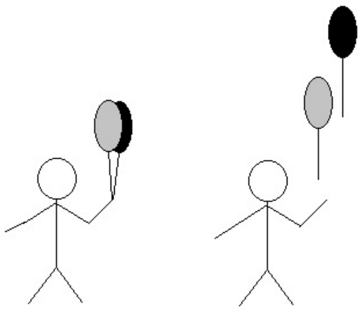
Because the picture in the pre-lesson assignment provoked student teachers to reply with colours and terms, such as wind, the author made a decision to exclude the picture from the post-lesson assignment. This was also done in order to avoid memorization. The post-lesson assignment had only the written question, which was the same text, though.

In the post-lesson assignment most of the student teachers left this question blank; only 12 student teachers replied. In five of the answers, the word helium was given, but no explanation why helium can be classified as something lighter than air (has a lower density than of air). Furthermore, flying was another term used to describe the concept. Also the following explanations were given

"*Some gases have lower air pressure than air, therefore they rise up. Some things such as peat weigh so little as possible so they don't fall to the bottom right away. People and animals try to be as light as air."* or

"*That e.g. feather can float because it is so light. It is held up by air."*

Figure 6. Two differently behaving balloons.



It seems that the picture given in the pre-lesson assignment helped the student teachers to form an answer of some kind. In the post-lesson assignment the student teachers from both institutes were mostly not able to answer. The few explanations given showed uncertainty. Also in the two answers above, although wrong, the student teachers gave a reason to their answer. However, based on the answers given in the pre-lesson assignment, the picture allowed student teachers to use their imagination instead of applying their knowledge to the answer.

On the other hand, based on the lessons given in both institutes, it was expected that the answers in the post-lesson assignments would be related to the temperature differences of air. Using warm and cold air as an explanation would have shown that the student teachers used the examples from the lesson. Then again, Bonnie's explanation of the concept did not have a clear conclusion in the end. Thus, the explanation was not finished and the connection between the concept and the explanation was not made sufficiently concrete.

3.6.6. Bernoulli's principle

The last question asked about the principle[16] by giving the student teachers four definitions (three wrong, one correct) of the principle. In the pre-lesson assignment all 35 student teachers replied to the question and 21 of them selected the right answer.

Both institutes demonstrated the basic idea behind this principle with an example. Below a transcript from the videos from the institute B is shown

> Bonnie: "*This is a way to demonstrate how an airplane flies.*"
>
> Bonnie brings from the side table two empty plastic bottles and a straw.
>
> Bonnie: "*I will soon blow air through the straw between the bottles. And then I want to know what you think will happen to the bottles. You have three possibilities: one: they go apart, they stay still, or they go together."*
>
> Explains once more what is about to happen.
>
> Bonnie: "*Who says they go apart?"*
>
> Bonnie counts hands.
>
> "*More than half of you say they apart. Who says there happens nothing?"*

16 The wings of an airplane are designed in such a way that the upper side of the wing is curved and the bottom side is almost straight. "When a stream of air flows past an airfoil (this case wing of an airplane), there are local changes in flow speed round the airfoil and consequently changes in static pressure, in accordance with Bernoulli's principle. The distribution of pressure determines the lift, pitching moment and form drag of the airfoil, and the position of its centre of pressure." Clancy, L.J., Aerodynamics, Section 5.5. Lift is a reaction force— According to Newton's laws of motion wings create a lift because they deflect the air flow downwards.

One hand rises.

"Who says they go together?"

Student: *"That can't happen."*

Bonnie: (Repeats) *"That can't happen."*

Bonnie blows air between the bottles and the bottles move together.

Student: *"See that!! Do you see that!!!??*"

Bonnie: *"So what happened?*"

Student: *"They went together."*

Bonnie: *"Yes!*"

She repeats the experiment and then points at one of the student teachers.

"Do you have an explanation to this experiment? This is the base why airplanes can fly and really heavy things."

Student: *"How come is that?"*

Bonnie: *"Yes? How come is it?"*

Student: *"Air goes..."*

Bonnie: *"Let's see…Student L says that it comes because of certain circulation of air...and...what happens then?"*

A transcript of the demonstration of Adam is given below. Before demonstrating the principle Adam had given the student teachers an assignment to place a small ball (made from tin foil) on top of a straw and then blow into the straw. The purpose was to keep the ball 'floating' on top of the straw, in the air, with constant air flow.

Adam: *"Flowing air has lower air pressure than standing air. That we can also observe from...the reason why we can fly. From a wing*."

He draws a big airplane wing on the board.

Adam: *"Here is a wing of an airplane or of a bird. And here you have* (draws arrows starting from the thicker part of the wing), *the air that comes from here, goes to the top. The air that comes from here* (draws another arrow on the flat side of the wing) *goes there. So this distance is short* (points to the bottom side of the wing) *and this distance is looong* (shows the top part of the wing). *So this air* (on the top part) *flows faster than the air underneath. This means that the air that is on top, there is less air pressure. "*

Student B: *"Than under…"*

> Adam: *"And therefore you have* (draws a big arrow underneath the wing) *that the air that is under, the air that stands still, pushes the airplane up. Or the bird."*

In the post-lesson assignment, instead of the multiple-choice question, the student teachers were asked to explain the basic idea behind the principle. Despite the fact, that both teacher trainees demonstrated the principle, only 28 student teachers replied to the question. Grouped answers are shown in Table 6.

The answers from the first group appear to be correct; however, the cause-effect reasoning is not complete. Similar findings could be detected in the previous question as well as in the research of Loverude et al. (2003). Loverude et al. showed that students failed to demonstrate through correct argumentation their understanding of the concept. Here, the answers miss the explanation of faster moving air that creates lower pressure that leads to pressure growth underneath the wing enabling lift to happen. Yet, these answers show an attempt to explain the principle. The rest of the answers are partial explanations of the principle or about the matters that make a phenomenon like lift to possible.

3.7. Discussion

This study acknowledges that an assignment has limitations to investigate concepts and possible false ideas. The given answers may not present the whole truth about the knowledge level. It was considered to include more open questions into the assignment, especially in the post-lesson phase. However, including multiple-choice questions assured more answers. The analysis is supported by video fragments from the lesson in order to have better and more holistic view on what happened. Additionally, it should be noted that a relatively small number of student teachers participated in this study and therefore, the results should be views as an indication only.

The above presented analysis is based on two single lessons, and similar to the student learning reported by Vosniadou and Ioannides (1998), the student outcome in here might have suffered from the lack of time reserved for explaining the concepts. Like in Chapter 2 not having enough time to learn the wanted concepts is clearly one of the problems. But yet again, since the time was a variable that could not be influenced within the framework of this study, a more pragmatic approach was to focus on the aspect of concept-context learning.

The student teachers need to be provided with adequate explanations of scientific concepts. The realisation that lift was falsely explained through Bernoulli's principle also demonstrates how easily 'misconceptions' are taught and learned, and how difficult it is to locate them. For the scientific explanations to be sufficient it is necessary to take into account their mental models and address their practically oriented beliefs (Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001; Milner, Sondergeld, Demir, Johnson, & Czerniak, 2012). However, according to Kegan, this may be more difficult to accomplish than expected since student teachers may be capable of abstract thinking, but they rely too heavily on designated authorities (as cited in Dunn, McCarthy, Baker, & Halonen, 2011). Therefore, they prefer more traditional learning methods, where a teacher provides the information and tells how to study. To students, only the given information is relevant and they do not value their own explanations to have a professional significance (Cady & Rearden, 2007; Francis, 1995) or they are never encouraged to do so.

In this study, both Adam and Bonnie demonstrated practical examples to the student teachers and attempted to include reasonable explanations in them. Where Adam demonstrated the same concepts to the ones asked in the questions, Bonnie tried to give broader examples and provide thinking skills. Bonnie taught almost the same concepts than Adam, but her students had to rely more on their understanding of the concepts when answering to the post-lesson assignment. Adam's students were given matching examples and this way they were able to repeat actual words and demonstrations in the post-lesson assignment. This suggests that the answers of the student teachers were dependent on the trainer's words. This hampers the interpretation of what the student teacher's own observations and knowledge are. After all learning to teach science requires understanding instead of learning how to use a specialized language or terms (Wenham & Ovens, 2010).

According to Mellando (1997) memorizing right words or sentences and using those without further thinking can lead to improvising in the classroom, using intuitive strategies and hardly any knowledge of science teaching methods. Nevertheless, the previous schooling may have shown to the student teachers that the best grades are accomplished by learning how to answer in an exam. Thus, practical, hands-on examples may not bring the wanted outcome. The interest in constructing one's own knowledge is not awarded enough and therefore, students have little motivation to independently ask questions and pursue practical approaches (Bencze, 2001). It appears that the student teachers are, due to the traditional

Table 6. Descriptions of Bernoulli's principle.

Types of answers	#
The air over curved part has a longer distance to travel and that's why a lower pressure. Lower part of the wing has higher air pressure therefore airplane goes up	4
Moving air has less pressure than standing air	4
Answers with a wrong example	8
Because of the form. Air on top goes faster/better/longer/slower than underneath	10
Curved wings	2

teaching paradigm, still passive recipients of knowledge (Paul & Elder, 2001).

In their book about teaching science in primary schools Harlen and Qualter (2009) encourage teachers to learn how to question whether evidence has been taken into account when explaining a phenomenon, and whether it makes sense in terms of relating factors. Here the analysis revealed that in both institutes learning does not happen in this way and forming an explanation is difficult. Hence, the student teachers do not or cannot notice the contradictions in their answers, similar to Loverude et al. (2003). This tight connection to an example reveals lack of understanding. The lack of explanation could be caused by the students not seeing explicit evidence important for an explanation (Sandoval, 2003). Instead, each question has a specific answer, and if that is not remembered then no alternatives can be developed through cause-effect reasoning either.

When asked to describe concepts of air, the student teachers tended to link their concepts of matter to tangible properties, very similar to findings of Davis et al. (2002). An equivalent indication of linking science concepts into practical, representational objects was observed in the answers of in-service teachers in the previous chapter.

When no clear example was shown during the lesson, the thinking followed similar patterns in both pre- and post-lesson assignments (see e.g. the answers to question 3, institute B). It appears that only exact examples resulted in answers. The trainers were occasionally unable to provide conclusions to their explanations and this can be one of the reasons why uncertain answers appeared. However, the student teachers might consider the lesson as a situation where they are handed recipe-like instructions on how to teach science in a classroom. If that is the case forming one's own explanation is difficult indeed.

The student teachers from the institute B focused on explanations, like "*air will be pushed under*" and "*air pressure becomes too big*", which indicate attempts towards own explanations. These answers nevertheless, lack logical thinking and the explanation is not drawn from reasoning. Yet, this could be due the absence of practice or inexperience of questioning the offered information. However, it is significant for doing science to know how to ask questions while doing. It is important to realize that the evidence is an important part of an explanation.

Furthermore, self-explanation is not seen as an important part of the learning although it provides a powerful method for enhancing understanding and conceptual change (Chi & VanLehn, 1991). It is evident e.g. from the answers given in question 3 "b*ecause air is blown in*" and "*it is possible to lift the books*" that the student teachers in both institutes are not used to explain. These types of answers only state the cause or the effect. How to think and solve problems can merely come through own thoughts; how to combine facts with practices. In both institutes student teachers were encouraged to think out loud in the classroom, but this happened in a less serious way, more in a form of brainstorming. This by no means is a bad approach, on a contrary. It, however, implies that more effort was needed in order to find the explanations that describe the situations.

It is encouraging to see that the student teachers were able to reflect on their professional skills and that they acknowledged their limited knowledge level (see answers to question 1b, Readiness to teach science). However, it is questionable what they meant when they stated that they need more knowledge about the concepts. Gomez-Zwiep (2008) concludes that most of the teachers are indeed aware of their false ideas, but they do not fully understand the impact of those to their instruction. Therefore, learning the concept does not automatically guarantee that one can teach it. It still can result to forming explanations from bits and parts. And if the learning is based on memorisation, the student teachers may not be able to notice the contradictions in their thinking.

When learners tend to rely heavily on the idea that the theories and practices are provided to them the learning will remain as an activity of simply getting usable answers. Therefore, a learning situation, where students would think of how to approach science problems at hand (Carter, 1990), is unreachable. Also, these systematic instructions on how to function prevent the development of a holistic perception to the topic, and block growth of transferable skills (Mioduser & Dagan, 2007). Furthermore, given that student teachers compare their ideas to the 'expert' lecturers, they will not develop an ability to reflect on their own teaching and practices (Bencze, 2001; Francis, 1995). This makes teaching how to deal with science even more demanding.

3.8. Conclusions and implications

The student teachers in this study answered the questions with the examples given by the trainer. These answers were related to tangible properties of the concept at hand. What the lesson tried to highlight was how to teach and learn with inquiry-based learning method. However, to be able to do this, the student teachers need to familiarize themselves with cause-effect reasoning and coherent argumentation, which the lessons despite the effort were unable to teach. At the moment only the exact examples of the trainer led to answers and this does not demonstrate understanding.

And what do these results suggest for the future teachers' education? In order to teach science as it is encouraged by the trainers and suggested in the literature, student teachers need to see beyond obtaining the recipe-like instructions and move on towards forming their own explanations and learn to ask questions. In this study if no matching example was presented to the student teachers the wrong ideas persisted or forming an answer was difficult. Without addressing the science topics with a concrete example relatively little change between pre- and post-lesson results could be seen. Therefore, teacher trainees need to address the topic with few examples that are clear and encourage student teachers to practice cause-effect reasoning.

Although the exact examples delivered the best results, cause-effect reasoning needs to be practiced. Instead of replying to their expectations by providing them with a viewpoint or an approach, the complex understanding should be nurtured (Paul & Elder, 2001). Because student teachers' ideas about teaching and learning are different than the conceptual change that is provided to them in their education (Abell & Smith, 1994), an approach where the student teachers are given enough space to form, ask and find an answer to their own questions is needed. The approach should introduce difficult concepts through tangible properties and offer a concrete explanation to a theory. This, however, should happen in phases where student teachers are helped to think by themselves. It is not enough that both the problem and answer are presented to them.

In the next chapter the last one of three studies is presented. To form the whole picture of concept teaching and learning in the classrooms, pupils' perceptions need to be investigated as well. Therefore, Chapter 4 moves away from the domain of teacher's concept knowledge and continues to investigate how a technology concept is taught to and learned by young pupils. Next chapter gives an interpretation of what the initial level of pupils’ systems thinking is. The possibilities of including systems thinking in a primary technology class are examined.

Chapter four

4. An exploratory study on how primary pupils perceive systems[17]

4.1. Introduction

Stud·y on pupils' concept learning is the last one of the three qualitative studies. The previous chapters have focused on primary in-service and student teachers' perceptions of science concepts. This chapter examines teaching of a concept to young pupils; namely systems (or systems thinking). Even though this dissertation is interested in teachers' concept learning, a study on pupils' concept knowledge is an essential addition to this dissertation. A study in education is only partially done if the researcher does not enter a classroom; observe and discuss how teachers teach and pupils learn.

Furthermore, the previous two studies have focused purely on science concepts. This dissertation, however, is interested in both science and technology concepts, thus, this time a technological concept is in the center of the attention. Secondly, the teachers work in classrooms with pupils. In order to paint the whole picture of science and technology concept learning, pupils' perceptions need to be investigated as well. And lastly, although a systems concept is stated to be one of the core concepts in technology education, little research has been done on pupils' intuitive notions about it.

First, in section 4.2 reasons to include systems thinking in to education are discussed. This is followed by a description of other studies in systems thinking, in section 4.3. Next, section 4.4 presents the aim of the study. In section 4.5 the participants and the school where the study was carried out are described. The framework is presented in the following section that is 4.6 and the research method is described in section 4.7. This study applied the teaching ideas of the model (introduced in the next chapter) for the first time to practice. Findings of the study are presented in section 4.8. Section 4.9 discusses how the level of systems thinking influences the approach of teaching the systems concept to pupils, and why teaching and learning this core concept may not be as straightforward as has been originally thought of. In the final section (4.10) a conclusion to the study is given.

17 Based on: Koski, M-I., & Vries, M. J. de (2013). An exploratory study on how primary pupils approach systems. *International Journal of Technology and Design Education*, *23*, 835-848.

4.2. Study into systems thinking

Children are natural systems thinkers, which means they can recognize interdependencies and interrelations of subjects long before they are taught to them in school (Booth Sweeney & Sterman, 2007). This type of integrated thinking allows them to include and gather information regardless of the discipline boundaries. By the time they are seven to eight years old, schooling has thus formed pupils' thinking so that subjects are seen as separate ones with no clear connection to one another (Senge et al., 2000; Sterman, 2002; Von Bertalanffy, 1979). Because in schools, subjects are strictly categorized, Booth Sweeney and Sterman (2007) discovered that students aged between 11 and 14 have limited intuitive systems thinking abilities. One-way causal thinking is characteristic of them and explanations lack a reference to time (Booth Sweeney & Sterman, 2007). Thus, this separation of subjects hampers perception of interdependencies and interrelations.

However, studies have also shown results of students aged between 12 and 14 making meaningful progress, from marginal systems thinking towards more holistic understanding of systems (Kali, Orion, & Eylon, 2003; Assaraf & Orion, 2005). Kali et al. (2003) explored and designed new activities to improve already existing learning program about rock forming. These new activities included, among others, inquiries of geological processes emphasizing the relationships between processes and their inputs and outputs. In Assaraf and Orion (2005) the students participated in a special program, which included 45 hours of laboratory and outdoor inquiry-based activities. These activities were specifically designed to assist students in developing systems thinking through learning about the water cycle and its environmental application.

The lack of systems skills is a result of teachers' inability to apply systems thinking in their teaching (Arndt, 2006). A key to improve skills of systems thinking is to expand these boundaries and increase the number of factors and resources considered (Sterman, 2002). Systems thinking offers tools and processes to cross our thinking boundaries and helps in expanding them (Sterman, 2002). Arndt (2006) also describes what a good learning environment should look like. It should integrate learning activities with larger concepts and tasks to authentic, realistic contexts and furthermore, refer these activities to matters relevant to students.

Literature has many definitions to offer on the concept of systems thinking, albeit similar to each other. Booth Sweeney and Sterman (2007) define systems thinking as a group of three abilities; understanding the parts of a system, the connections among these parts and seeing a system as a whole. O'Connor and McDermott (1997) have a similar definition, with one additional ability; understanding the parts by studying the whole. Another definition of systems thinking divides the concept into seven different types of thinking skills; dynamic, closed-loop, generic, structural, operational, continuum, and scientific thinking (Richmond, 1993). In an online source Ossimitz (1997) lists four skills that are important for thinking in a systems way: thinking in models, interrelated thinking, dynamic thinking, and steering systems (system control).

The current perception of systems is moving towards the socio-technical viewpoint. Systems are seen as multiple purposeful actors and material artefacts interacting in a way that it is impossible to separate them and analyse only parts of the whole (Bauer & Herder, 2009). According to this view, technical factors are considered less important and the emphasis is on the influence of social actors on technological developments (De Vries, 2005). Although the social aspect of systems is relevant, this study concentrates on the engineering side of systems and systems thinking supporting technological designs. The engineering aspect allows us to familiarize ourselves with the concepts that engineers use to design new artefacts and this offers technology a way to understand why things function as they do (De Vries, 2005).

4.3. Importance of systems concept

Systems are an important concept in contemporary technology. Thinking in terms of systems provides a tool to grasp the complexity of situations (Westra, 2008, p. 66) and helps to understand that incidents are not isolated and independent but a part of bigger patterns (O'Connor & McDermott, 1997). Systems thinking provides universal models that can be used in, and transferred to different disciplines (Barak & Williams, 2007; Von Bertalanffy, 1979). In general, without knowledge of systems thinking individuals tend to describe situations with surface features (Booth Sweeney & Sterman, 2007).

If schools want to present an up-to-date image of what technology is, then concepts surrounding systems need to be considered as an integral part of technology education. In the Standards for Technological Literacy systems are listed as one of the core concepts for the study of technology (International Technology Education Association [ITEA], 2007). By including systems thinking into education a broader knowledge of technological artefacts could be introduced to the students. Development of technological systems offers pupils opportunities to understand, practice, influence and engage with technology (Svensson, Zetterqvist, & Ingerman, 2012). According to ITEA (2007) students (11-14 years old) should learn that technological systems include input, processes, output and feedback. Systems thinking also teaches to consider how every part relates to one another.

The concept of systems is mentioned as a key concept in technology education although no effort has been made to investigate how young and adult people perceive this concept (De Vries, 2005). This chapter reports a qualitative study on primary pupils' systems thinking, focusing on the basic building blocks of systems. An investigation of pupils' perceptions and how they approach systems is presented. Central research questions are:

1) Can an evidence of 'seedling' of system thinking be found among young children and

2) Can an indication of 'misconception' be found?

The purpose of the study is not to show which are the right thoughts and good approaches, but to find elements of systems thinking. In other words, to comprehend pupils' level of systems thinking and to have an idea of what to expect when introducing systems thinking in to primary education.

4.4. Aim of the study

Children's pre-concepts about systems in the field of technology have not been the subject of many studies yet. This chapter gives an interpretation of what the initial level of pupils' systems thinking is, and examines what the possibilities of including systems thinking in a primary technology class are. The study uses the definition of systems thinking provided by Booth Sweeney and Sterman (2002). However, instead of deciding how the correct systems thinking should look like, this chapter presents intuitive thoughts and ideas of pupils; how do pupils see systems and are there elements of systems thinking in pupils' approach. The investigation focuses on how pupils see input and output, whether they recognize different parts within a system and how they define boundaries to these systems. If a pupil recognizes that a coffee machine requires water and electricity in order to produce coffee, this shows elements of systems thinking. Realizing that inside a washing machine, different parts function in a certain order to get clothes clean, demonstrates systems thinking as well.

This study acknowledges the earlier mentioned socio-technical viewpoint as well as that of integral thinking, both important and close to our viewpoint. However, here the systems are approached from the engineering point of view. Therefore, basic building blocks and pre-concepts of systems are investigated and further analysed. A successful systems teaching acquires investigations of what the level of systems thinking in the whole classroom is. For this reason before pupils' systems concepts could be tested, the teacher's knowledge level on systems was investigated as well. This was also done to increase her confidence and abilities to use the new approach in the classroom (Arndt, 2006).

4.5. Participants and a description of the school

The study was conducted among 27 pupils (8-10 years old) and their teacher. Six of them, four girls and two boys, participated in the pre-lesson interview. Because the teacher did all the interviews, and each of these took approximately 15-20 minutes, it was not possible to interview all the pupils within the given timeframe. The study took place during the winter months of 2011-2012 in a Dutch primary school as a part of a technology class.

The teacher was familiar with working together with university researchers and she was open to discuss and experiment with new ideas. She was comfortable in having outsiders in her classroom and giving different design lessons to her pupils. However, the concept of systems was new to her and nothing in her classroom would stimulate the pupils towards systems thinking. The pupils were used to work in teams and they had prior experience in designing. Pupils, such as these, benefit especially from adding a systems thinking approach to their design process. It helps predict the outcome and control the process.

Often, during the lesson the teacher used a method where she put a stopwatch on, on the SMART Board for a specific amount of time (typically three to five minutes). The pupils were accustomed to checking how much time they still had to execute the task and they stopped what they are doing when they heard the alarm of the stopwatch. This helped the design project to stay within the time limits, and it also provided boundaries and structure to how much time the pupils could use per task. Of course if the time was not enough the class discussed together what still needed to be done and how much additional time was required to finish the task at hand.

The school itself was relatively new with modern classroom facilities. Teachers had a computer and a SMART Board in their classrooms. The school was one of the few ones in the Netherlands that also have a kindergarten in the same building.

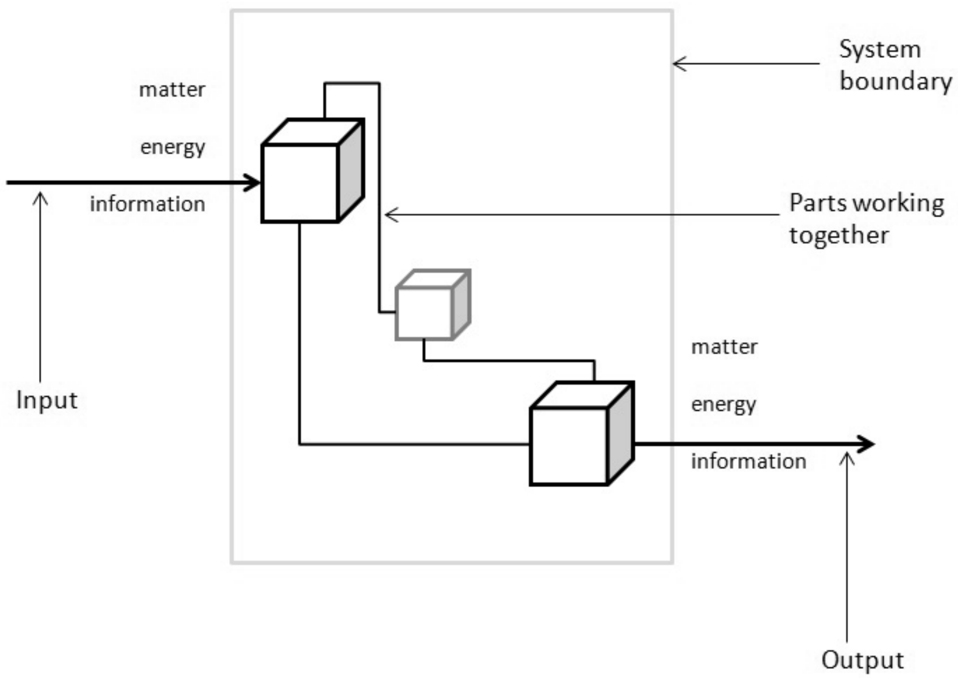
4.6. Research framework

The framework (Figure 7) focuses on practical aspects of a system and is built on three notions about systems themselves. ITEA (2007) defines systems as: "a group of interacting, interrelated, or interdependent elements or parts that function together as a whole to accomplish a goal". O'Connor and McDermott (1997), as well as Booth Sweeney (2011), compare a system and a heap[18]. One of the crucial differences they draw attention to is how parts are connected and how parts work together in a system, unlike a heap where they do not. Together with the definition by ITEA and this dichotomy, a notion of a main part and subparts, and these parts working together was formed (this also appears in the concepts of systems thinking). The idea is to see whether pupils have a tendency towards a black-box type of thinking about machines or do they recognize a connected structure underneath the cover of a machine.

The second notion is systems having an input and an output. Here, De Vries (2005) refers to German text books, in which inputs and outputs are defined as a

18 A heap is structure where parts are allocated and removed in arbitrary order.

Figure 7. Research framework and its components



set of three components: matter, energy and information. This categorization was used to investigate if pupils have an idea about inputs and outputs, and what they considered them to be.

The third notion is the boundaries of a system. O'Connor and McDermott (1997) write about understanding and limiting the complexity of a system by defining clear boundaries to it. Here the definition was used to reveal the degree of pupils' understanding to what is meant by a system. Knowledge of the system boundaries indicates the understanding of the complexity of a system.

The abstract definitions and concepts presented here are included for the purpose of data analysis and to direct the research. The teacher and the pupils were never asked to describe systems in such detailed and abstract way. Following list demonstrates how answers were interpreted to correspond to the abstract definitions. Words or terms in italic refer to the answers given and ones in parenthesis refer to the abstract term or a rule that was used to interpret the answers.

> IN- or OUTPUT: *water* and *clothes* (matter), *heat* and *electricity* (energy), *time* and *press a button* (information)
>
> PARTS WORKING TOGETHER: *"Make water warm, open a small tube, the coffee is going through something, a valve opens, a cup underneath, then coffee comes out."*
>
> SYSTEM BOUNDARY: "*Detergent, door open, wash in, door close, how many degrees, put it on, turns, waiting, ready, door open, wash out, door close, put it off*." (All the actions are performed within the systems boundaries (of a washing machine))

4.7. Method

Like the other studies in this dissertation, this study is qualitative in nature. The main purpose was to get a first impression and general knowledge of the pupils' systems thinking. The study was designed in a similar manner as suggested by Tiberghien (1997), where data are gathered in two phases. First, an idea of what the learnable part of knowledge is needs to be acquired. This is done by analysing students' prior knowledge and the knowledge that will be taught at the lesson. In the second phase, the different aspects of teaching situation are analysed by focusing on the teaching session and the student progress during that session.

Hence, this study (Figure 8) started by designing and implementing a 'pre-test'. This was more of a structured interview to investigate the already existing thoughts and concepts on systems before any introduction to the topic was given. The teacher's strong role in the study was due to the author's wish to stay as an outside observer as much as possible. The teacher's thoughts were tested by asking the teacher to explain three scenarios and one abstract definition about systems (see Apendix C)

1) What is the difference between a line of dominos and a stack of dominos,
2) How does a coffee dispenser at the train station work (What are the steps needed in order to produce a cup of coffee?),

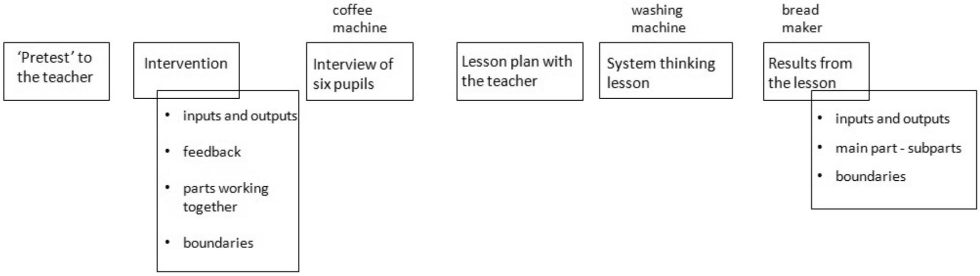
3) How are a producer, a market and a consumer connected (how are they linked, what type of links?), and

4) What is a reinforcing feedback? What could be a situation from every-day life, where it could be applied to?

A few weeks later, based on the teacher's answers, a session explaining systems thinking took place (Figure 8: Intervention). This was done to assure that the teacher's ideas about systems and systems thinking were on the same level with the author. In this session 'correct' answers were given and the underlying systems concepts were discussed with the teacher. This session was designed to explain systems thinking to the teacher, the concepts, as well as the basic concepts that she would later on apply in her classroom. This was a loose way to apply the method of the model (Chapter 5) in to practice for the first time.

During the intervention the teacher said that she started to view her surroundings in a different way. She expressed that the realization that systems are everywhere was new to her. She admitted that she never viewed in- and outputs as a set of three components; matter, energy and information. She enjoyed the realisation of feedback from the example of filling a glass under a faucet (a faucet is turned on, the water level starts to rise, when there is enough water in the glass, an eye sees this; a feedback from the water level to an eye, and based on this hand closes the faucet). She told that she never thought of a simple everyday life action as an example of system. Furthermore, the teacher explained that the pupils had no prior experience of the systems concept and that she was excited to try to teach such a concept to her pupils.

Figure 8. Design of the study.



The actual data[19] consist of all the parts (six smaller rectangulars) presented in Figure 8; the intervention and the lesson plan have a more supporting role, though. Three home appliances were used to investigate how pupils perceive systems; a coffee machine, a washing machine and a bread maker. Boersma, Waarlo and Klaassen (2011) recommend testing systems thinking with objects that have distinct systems boundaries to limit possible misunderstandings and this way to have the correct ideas of pupils' systems thinking abilities. This in mind, these three appliances were chosen together with the teacher.

Before the lesson, six of the pupils participated in an interview, where they were asked questions about coffee machines (more detailed description of the 'pre-test' will follow in the next section). Based on the intervention, the discussions with the teacher and the results of the interview with the pupils, a lesson was designed together with the teacher. A month later, a 70-minutes lesson was given and the topic of the lesson was to show a washing machine from a systemic point of view. All 27 pupils were encouraged to use all of their senses to collect information about washing machines, and brainstorm about ideas related to washing clothes. With this the teacher tried to emphasise all possible in- and outputs that a system can have and this way make the children aware of them as well. During the lesson the teacher and the pupils discussed the different stages of doing a wash and how different parts of a washing machine are involved in these stages. The teacher also made the pupils think about different parts working together and how they influence each other.

Furthermore, at the end of the lesson, the pupils wrote down what goes into a washing machine, what happens then (when the laundry is being washed) and what comes out in the end. After a few days, the pupils were given the first version of the post-lesson assignment. This assignment asked them to design a system that helps them with a task that they need to do daily. However, the assignment turned out to be too open. Two weeks later, the same 27 pupils were given another assignment to draw and explain how a bread maker works, in the same manner as with the washing machine earlier. Both the interview with the pupils and classroom activities were videotaped.

4.8. Findings

The results of the pupil interview, lesson, and post-lesson assignment are presented here. The interview questions, for both the teacher and her pupils, were concerned with how a coffee machine works. In the lesson, the pupils investigated the elements of a washing machine and the process of doing a wash. The post- lesson assignment was about applying the ideas that evolved during the lesson to another machine; namely a bread maker.

In this analysis, the answers of the pupils were at the centre of the scope, and the teacher was used as an explaining factor. For instance, in the feedback session after the 'pre-test' of the teacher, most of her questions were about inputs and outputs. Discussions about the inputs and outputs influenced the teacher's view of systems (see 4.7), and also how she asked and directed the questions during the lesson. This is taken into account when viewed the answers.

19 The material and answers are translated from Dutch and checked together with Prof. Marc de Vries.

4.8.1. Interview

In the interview, the pupils gave similar type of descriptions concerning the systems. The author has selected the answers that describe certain phenomenon the best to be presented in this analysis. Furthermore, the answers that showed something that the other pupils did not mentioned are included as well.

The interview sessions started by pupils making cups of coffee in the teachers' lounge (Picture 1). Subsequently, the teacher asked them if they had ever made coffee and if yes, what kind of coffee machines they used. All the pupils participating in the interview had used at least one type of coffee machine and all of them regularly made coffee for their parents at home. Some of them even knew how their parents make coffee at work. Discussions occasionally got competitive when the pupils described how many different machines they were familiar with and had used.

The following extract presents a part of a discussion about what is required and what the machine does in order to make a cup of coffee.

> Teacher (T): *"What more is needed?"*
>
> Boy (B): "*Hot water, I think.*"
>
> T: "*Did you see where the water came from?*"
>
> B: "*Hmm…*" (the boy hesitates)
>
> Girl (G): "*Through a cord.*"
>
> T: "*What more is needed? What happens first?*"
>
> B: "*I heard that it first waits a bit... hmmm...Yes, then I think there are some preparations...*"
>
> T: "*What are these preparations?*"
>
> B: "*Hmmm, that the beans are grinded.* "

In this extract, the boy mentioned water (matter) as an input to the coffee machine. The boy however, overlooked steps in the process by starting with hot

Picture 1. Top: pupils making coffee. Bottom: answering questions about the same machine.

water. He did not mention how the water is heated or how it is 'inserted' into the coffee machine. Earlier, he had explained that at home he uses one type of coffee machine and in that short explanation he mentioned that the machine needs to warm up the water. Here, he took the existence of hot water as given and although the girl mentioned that the water comes through a cord, he went on to talk about the other preparations that need to be made. Similarly to Arndt (2006) stating one type of input satisfies pupils and further inputs (or outputs) need an initiative from the teacher, as can be seen below.

T: "*But, feel the cup. It is warm. Why do you think that is?*"

B: "*Because there is boiled water.*"

T: "*I don't know if there comes boiled water out of the faucet...?*"

B: "*No.*"

G: "*I think the coffee stays warm because of the cup.*"

T: "*But it is outside of the machine. Is the cup warmed first?*"

G: "*No.*"

T: "*No, but still it is warm...? I think it is because the water is warm, but where is the water made warm?*"

B: "*What I think is that this machine is like a thermos can. The water comes there through the cord and then the water stays there* [in the coffee machine] *warm and then it comes out warm.*"

Here, the teacher knew about the other types of inputs and outputs. Therefore, she tried to trigger the pupils to think about them as well. An output, heat (energy) appears here as well. The reason though why coffee is/stays warm was approached the wrong way round by the girl. Similarly to the boy, she was not concerned about how the machine makes warm coffee, but how to keep its temperature. However, this conversation prompted the boy to think about the steps, which the coffee machine needs to go through. He applied the answer of the girl and stated that the water comes through a cord. Then he continued by explaining that the coffee machine resembles a thermos can, and that keeps the water warm. Hence, there is a part controlling the temperature of water in the machine.

Additionally, all the pupils included grinding of the coffee beans into the process. In the first extract, the boy thought of it as part of the preparations. Yet, it stayed unclear whether it is a task of the machine or the user.

In the next extract, the girls considered more required inputs for the coffee machine to function.

Teacher (T): "*What do you need to make coffee?*"

Girl 1 (G1): "*Warm water, flow* (a Dutch word stroom can mean a flow of water or electricity) *through the coffee powder …*"

T: "*What do you mean with the flow?*"

Girl 2 (G2): "*For the plug* (electricity)."

T: "*And what is the electricity needed for?"*

G2: "*To warm up the water.*"

G1: "*For it to function, if you press the button, something is going to happen."*

The girls listed all three types of inputs: water (matter), electricity (energy) and pressing the button (information). The only output mentioned was the coffee coming out. These girls mentioned warm water as well. The difference to the previous pair is that these girls mentioned that electricity is needed in order to do so.

In the following part the girls were invited to think about the process of making coffee. They described a linear process, with no feedbacks. Nevertheless, different phases and parts doing something together appeared in the description.

T: *"What steps will the machine follow?"*

G2: *"Make it* [water] *warm, and then it* [coffee machine] *is going to open a small tube."*

G1: *"The coffee is going through something so that there won't be any pieces in the coffee."*

G2: "*And then opens a little valve."*

G1: *"And you have to take care that there is a cup underneath."*

G2: "*And then it* [coffee] *comes out."*

Before addressing the actual systems thinking questions the pupils expressed expert-like detailed descriptions on how they make coffee at home. This knowledge however, was not used to answer the interview questions. In the research by Fox-Turnbull (2012) the pupils deployed knowledge, which they had obtained by interaction with artefacts at home to the design tasks at school. Fox-Turnbull (2012) uses the term *participatory enculturation*, which means that students gain knowledge from their home and community and bring this to school and to learning situations. Here, pupils were unable to connect and use the knowledge that they already had to reply the questions. They did mention grinding the coffee beans, but on the other hand that did not fit to the description of the coffee machine at hand. Although, the loosely structured interview allowed pupils to brainstorm together to come up with the answers, it cannot be compared to the hands-on design situation, where pupils more likely feel in charge of the task and free to explore.

4.8.2. During the lesson

In the beginning of the lesson, pupils received a closed envelope, which they could not open.

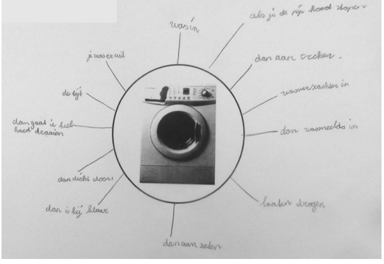
They could only smell through holes on the envelope to guess what the content of the envelope was. The pupils were asked to write down what they smelled, and what it could be used for (envelope contained washing powder). After this, the pupils were invited to talk in groups of four of what they had smelled, and to write down a group answer. After the discussions, the pupils told their answer to the whole class and the teacher revealed the correct answer.

The warm-up session was followed by a short “history” of washing machines and how our grandmothers did laundry. This part triggered pupils to discuss several topics regarding doing laundry, such as “*What does a centrifuge do?”* Afterwards, the whole class participated in a brainstorming session on how a washing machine works. Here, the pupils were asked to describe what they can hear, see, feel and smell when a washing machine is on. Finally, the pupils wrote down individually what goes into a washing machine, what does the machine do, and what comes out (what is the end result) (Picture 2).

The answers were mostly about what goes in. Generally, the lists included fabric softener, detergent, clothes and water (matter). However, also electricity (energy), time and pressing buttons (information) were mentioned.

To the question “what does the machine do”, none of the pupils described the different phases a washing machine goes through. They commonly observed it from their point of view: “*It turns around very hard*”, “*Wait*”, “*You feel shaking*”, “*It turns hard so that the water goes out from the clothes*”, “*Noise*”, “*The wash turns a lot, water mixes with detergent*”, and “*Moving*”. Answers such as moving and noise are influenced by the assignment from the beginning of the lesson, where the pupils were asked to imagine what they can sense when a washing machine is on.

Picture 2. Example answer about the washing machine.



Answers also included straightforward lists of steps to do:

> “*Detergent, door open, wash in, door close, how many degrees, put it on, turns, waiting, ready, door open, wash out, door close, put it off, put it in the dryer, put it on, waiting, ready, wash out, put it off*.”

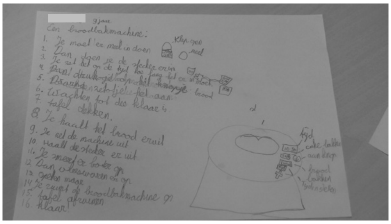
Answers such as the above are again from the user’s point of view. However, an interesting addition to the list can be observed. While the assignment asked about a washing machine, the pupils included steps like: "*Hang them on a line*", "*Let them dry*", "*Put them into the dryer*", and "*Laundry room*". This indicates difficulties in setting boundaries to a system. All of these actions that appear outside the system boundaries are actions that happen after the machine had executed the steps. Mostly, such answers were concerned with drying the clothes. Some of the pupils even included folding the clothes and putting them into a closet, within the system boundaries.

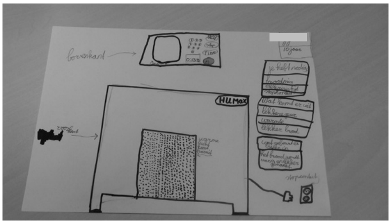
Unlike the inputs, the outputs were about 'end products': "*Clean laundry out*" or "*Wet clothes out*". However, heat, an electricity outlet and soap foam were mentioned as well.

Based on the answers given, the exercise where the pupils were invited to use all their senses to gather information had the biggest impact on them. Triggered by it, the pupils started to consider more options for input and output. In the interview the answers were more random and suggested that they were the first ones that came to the pupils' minds. This was of course the purpose of the interview to get as many descriptions concerning the coffee machine as possible. The answers after the lesson were more 'sophisticated'. Compared to the interview, the list of steps that a washing machine goes through was more detailed than the explanations of the steps of a coffee maker.

In general, the teacher was satisfied with the way she was able to teach a new concept to her pupils. Besides that she was pleased to see that the pupils were so eager to discuss the different parts of a wash machine with her and think about the system together.

Picture 3. Example answers about the bread maker.





4.8.3. Post- lesson assignment

In the post- lesson assignment, the pupils drew and wrote, in a same manner as with the washing machine question, how a bread maker works (Picture 3). The answers covered different types of inputs and outputs. Naturally, bread mix and flour were the most popular ones; however, the electricity outlet and buttons were among common replies as well. Contrary to the answers concerning the washing machine, surprisingly many of the pupils replied that a bread maker will not function unless it is plugged into an outlet. An explanation to this could be that a coffee machine is possibly seen as a standard kitchen appliance and does not need to be plugged in every time it is used, unlike a bread maker that is more likely to be stored in a cupboard. Furthermore, the pupils were invited to draw their bread makers and this may have caused them to sketch buttons as well, thus being part of the inputs.

As far as outputs are concerned, almost all the pupils mentioned all three types: bread (matter), smell (information) and steam (energy). Warmth and some sort of sound indication when bread is ready were included as well. The earlier assignment to use all senses likely helped include such outputs.

To the question "what happens inside the machine", pupils included replies such as "*the bread is made inside*" or "*the machine mixes the flour*". However, there was no clear indication of specific parts working together. As machines, a coffee machine has visibly clearer structure than a washing machine or a bread maker. Therefore, the pupils could have observed different sub-functions that a coffee machine goes through, but in the other two cases, everything happens behind/under a closed lid. What happens inside a machine was a challenging question for the teacher as well; therefore, this aspect of the study did not get the required attention.

Furthermore, some of the pupils mentioned the whole procedure from pouring the flour into the machine all the way to eating the bread and cleaning the table. The following list is an example of this, given by one of the pupils:

> *"A bread maker: 1. You have to put flour in. 2. Then you plug in the plug. 3. You set the time how long it needs to be in. 4. Then you push the button. 5. Then you put it on. 6. You wait until it is ready. 7. Set the table. 8. You take the bread out. 9. Set the machine off. 10. You unplug the plug. 11. You spread the butter on top. 12. Then you put the sliced cold meats on top. 13. Eat it. 14. You clean the bread maker away. 15. Clean the table. 16. Ready!"*

The system boundaries were extended to what happens after the bread maker has made the bread. It seems that separating the tasks between a machine and a user was still problematic to some pupils. Hence, the system boundaries are unclear.

In this extract an additional finding can be observed. The pupil described a waiting time until the bread is ready (step 6). In the case of the washing machine similar statements were observed but they were vague compared to this one (wait or waiting). This sentence indicates that the machine needs to give a sign when it is ready. Hence, there has to be a feedback from the machine that the user receives. However, since this was a written answer (no additional questions) it is difficult to determine for sure whether the pupil merely knows that the bread cannot be ready in a minute, or that the bread maker gives a sign when it is ready.

4.9. Results and discussion

The purpose of this study was to investigate the extent to which pupils have an intuitive knowledge of systems; to see what the level of system thinking is and to give an idea of what can be expected when applying systems thinking to classroom activities.

The interview and the lesson showed that the concept of input is more obvious to the pupils than the concept of output. With teacher's help the pupils came up with more outputs but often the obvious function of the machine (what it does or produces) was the only feature considered and no further thinking was deemed necessary. In the post- lesson assignment, inputs were mostly viewed in a similar manner as before; generally, inputs were related to matter but also energy and information were mentioned. The most notable change had occurred with respect to outputs, where all three categories were now included.

The pupils were not able to explain relations connecting inputs, processes and outputs, like students in Ginns, Norton and McRobbie (2005). In their study, the students participated in a unit of work aiming to design and construct simple systems, followed by experiences of more complex systems. This changed the students' abilities to identify individual components, components working together and outline sequences of cause and effect (Ginns et al., 2005). However, these students were in general two years older than the pupils in this study. Also the way post- lesson assignment asked pupils to draw and write on their drawings, does not necessarily invite to act in such a way.

One-way thinking, similar to the findings of Booth Sweeney and Sterman (2007), can be observed from the answers. There is no clear indication of whether the pupils saw machines as something with a main part and subparts working together or not. Some comprehension of a part functioning inside another or sequence of steps can be observed in the interviews. However, for this to happen, a push from the teacher was required. Machines were mainly described in terms of what the user can experience, instead of what the machine itself does. The comprehension of what a system and a user do, seemed to overlap, and this made setting the boundaries around a system more demanding.

This study is a small sample, but the results show that systems thinking can be included in the design class and that the thinking boundaries (Sterman, 2002) can be, if not crossed, expanded with a relatively straightforward lesson plan. After explaining the basic principles of systems thinking to the teacher, she was able to show the pupils a different approach to a problem. And instead of settling for a fair description of what the machine does, the pupils used other approaches to explain and label important artefacts.

Based on the findings, the difference between what a user and what a machine does needs to be made clear when teaching the systems concept. It appears that pupils did not comprehend structures with sub-tasks and parts working together. Therefore, all the tasks were approached through actions. These actions did not require information of who does what and that leads to vague system boundaries. To help pupils with setting the correct boundaries to a system, it is essential to make a distinction between notions like 'a washing machine' and 'doing a wash'.

What followed from unclear system boundaries was the difficulty to define inputs and outputs. Introducing inputs and outputs to pupils by approaching them through tangible properties of these two might help realizing them. Matter was the easiest; therefore, should be introduced first. Information seemed to be the most difficult one to realize. It acquires further attention and should be dealt with later.

The analysis revealed that pupils have difficulties in determining the difference between a process and a system. This naturally makes setting boundaries around a system more challenging. Difficult as it may be, setting the right boundaries around a system is crucial for the design process. Pushing or limiting the original boundaries may bring whole new aspects into the design process. One way to emphasize the difference between a process and a system could be to introduce the pupils to a system that can be used in two different ways. A Smartphone could be as such a system, where the same artefact can be used to make a phone call and to take a picture. An extreme example would be to compare a washing machine doing a wash and using the same machine to mix concrete. These examples show systems that pupils are familiar with used in a standard and an unconventional way. Maybe this helps to introduce the concept of process in relation to what is meant by the systems concept.

Future study with larger samples is necessary to properly understand systems thinking abilities of young pupils. Systems thinking skills are still barely used by teachers (Arndt 2006). Thus, more teachers need to be invited to use methods like the one presented in this study in order to introduce systems thinking to their pupils. The suggested method of showing pupils familiar systems (Smart phone and washing machine) used in a standard and unconventional way might help them to develop their systems thinking abilities. However, this should be just a starting point and an example for the teachers to start creating their own approaches. On the other hand, also teacher training programmes could introduce systems concept to future teachers in their training programs. Further investigation of concepts such as feedback and system boundaries would provide much needed deeper understanding of young pupils' systems thinking.

4.10. Implications for systems thinking education

Based on the analysis, it can be concluded that the pupils' approach towards systems was limited. They often addressed the system at hand from a linear point of view with the emphasis on experience gained by using it. The descriptions followed similar appearance as e.g. their mothers would tell them to do their chores and the pupils recall the behaviour and actions from it. In these experiences, systems are used as an aid to execute a certain task and the end result is the aspect that matters. During these processes pupils never had the need to look under the lid or look inside the machine; in other words to open the so-called black-box. This type of approach is natural since this has been the only way pupils have interacted with systems. We need to be aware of this linear, user-driven process-type of approach because it hides systems thinking and focuses only on what can be seen and experienced by using the machine.

The concepts that the pupils have described here are not necessarily misconceptions. They are concepts that are based on their experience of what works in their world. Because their experience has proven that these thoughts and ideas explain the concepts sufficiently, there has been no need to change them in their everyday-life. Therefore, they need to be taken as pre-concepts and as a starting point for a lesson plan to see how to approach and include systems thinking in the technology class.

The difference in how the example machines can be observed has an influence how well the pupils can describe its functions. The difficulties in defining system boundaries and different parts working together force the task to be concrete and the topic preferably something already known. In the data collection phase, instead of the bread maker, pupils were first given a task to design a system that helps them with homework, or with walking the dog etc. This however, did not bring the wanted answers. The pupils were not able to think in the intended way, their focus was on what the machine could be about, and what would be the funniest one.

Now that concept learning has been investigated from three different perspectives, in the following two chapters a possible solution to the issues detected is offered. The next chapter will present an exploration to help teachers in teaching and learning science and technology concepts. The idea was to design a model that would help teachers to plan and give lessons concerning concepts in science and technology. Chapter 5 describes this development process. The learning and teaching model is based on theory as well as on existing teaching situations.

Chapter five

5. A model to connect domains in concept learning[20]

Knowl·edge level of science and technology concepts directed the research in the previous three chapters. They have given an idea of what the knowledge of science and technology concepts in these three cases was and what the possible factors hampering teaching and learning could be. The in-service teachers' pre-concepts did not match with the ones used and taught in science and technology. The student teachers did not form their own knowledge of the concepts taught, but instead settled for repeating the exact examples taught to them by the trainers. The young pupils' intuitive knowledge of systems was limited and the pupils often approached the systems from a linear point of view with the emphasis on experience gained by using the system.

However, in all the three studies the tangible properties of an object were mentioned. The main problem seems to be that the theory provided and practice to apply it to do not connect and they stay as separate domains. Thus, science and technology education could benefit from an approach where different types of knowledge work together.

This chapter introduces a three-domain model for concept learning[21]. The model emphasizes combining and connecting practical and abstract knowledge throughout the learning process. Unlike other learning models or approaches, this model distinguishes three domains: the social context, the concrete product and concepts.

The development of this approach began with a literature review and an analysis of existing learning models. This is presented in sections 5.1 and 5.2. In section 5.3 the model is used to analyze, explain and improve learning situations that occurred in a professional training for primary teachers. Section 5.4 continues to do the same but this time exploration focuses on how the three domains can be used in the development of creative

20 Based on: Koski, M-I., Klapwijk, R., & Vries, M. J. de (2011). Connecting domains in concept-context learning: a model to analyse education situations. *Design and Technology Education: an International Journal*, 16(3), 50-61.

21 The idea of the model and the development of it are done together with Dr. Remke Klapwijk. This chapter uses the theory presented in the journal publication. The data presented in this chapter belongs to the author, unless mentioned otherwise.

design solutions. The section 5.5 discusses how continuous movement between the three domains is needed to develop creative, socially relevant solutions. The discussion draws the attention to the connections between the domains and furthermore, how teacher training could be better aimed towards the needs of a learner if these connections between theory, concrete experiences and social context were made more visible and inviting. Finally, in section 5.6 the conclusion is given.

5.1. Introduction

Presenting science and technology concepts through themes that make sense to learners; themes that are closely related to their everyday-life, provide an educational approach that is more comprehensible towards real problems and concrete objects than an approach that aims at teaching at an abstract level right away. The social context that comes with this approach offers a problem-solving situation to which learners can easier relate than to a theoretical formula. This also fosters positive attitudes towards science (Bennett, Lubben, & Hogarth, 2006). However, it is not clear how abstract and practical knowledge should be combined so that both concept learning and the development of creativity are supported.

The combination of theory and practice in concept learning provides an interesting field to be explored. This chapter introduces a model that enables the learned concepts to be more effectively applied in real-life problems. Based on the research presented in the earlier chapters, a three-domain model that helps to create a set of learning situations linking social context, concrete object and abstract knowledge is presented. Using these three domains, concept learning is enhanced without ignoring creativity and (real-life) problem solving. This idea of the model is demonstrated through examples from an in-service training of primary teachers.

5.2. Literature study for the model

How are science concepts related to concrete real-life situations? What are the relevant knowledge domains that are ideally included in concept learning situations? To form an answer to these questions, literature from various fields, such as design and technology education, design methodology, technology philosophy, creativity education and inquiry-based education is combined.

Keeping the learning situation strictly focused on facts and solid, well-tested topics is a common approach in concept education. This has its benefits of explaining the concept precisely without experiencing difficulties of unexpected outcomes. However, concept education does not need to be an isolated event; it can be used alongside the existing approaches. Design processes are an example of creative problem-solving processes where learners apply both concrete and abstract knowledge in the product design activities. The coexistence of these two types of knowledge; concrete product knowledge and abstract knowledge is not only relevant in inquiry-based learning activities. It can be just as well used in design and technology education. As a result, learners do not only understand the concept at a higher level but they increase their abilities to apply it in real-life situations simultaneously.

Since science and technology education should prepare students to be able to participate in society's technological decisions (Introduction, Chapter 1), it seems reasonable to teach these concepts in those contexts that appeal and are meaningful to the learners. Learning in and through these social contexts was introduced by Vygotsky (1978). He claims that humans learn through being and acting in a cultural context and in a sense they re-invent the learned matters in that culture (Crawford, 1996). According to Vygotsky, learners build cognitive structures through needs, purposes and actions, through their relationships with other people, and they attach meanings to the activities (Crawford, 1996). This same underpinning of needs and purposes is presented by Knowles, Holton and Swanson (2011) in the theory of Andragogy when they state that adults need to know why they are learning what is taught to them. Knowles et al. (2011) do not talk about social context, but they state that adults relate learning to their previous experiences and lived life.

Designers also recognize the importance of right social context. Successful designing has to be well aware of the specific social context and the various actors that will be put in touch with the products. Philosopher Ropohl (1997) emphasizes the importance of social-technical knowledge. He indicates that designers use knowledge about the social context as well as insights of the interrelationship between the technical objects and their social meaning. Vincenti (1990), who studied design practices in the aircraft industry, points towards (design) criteria and specifications. These criteria originate from the social context but are often formulated in physical terms.

The physical terms are the ones that define use, function etc., of objects and products. In concept learning the concrete objects used are often influenced by the daily life of the learner (e.g. balloons or a kitchen-scale), but also specific measuring instruments (e.g. pH meter) are used. It is assumed that learners are most likely to develop an in-depth understanding of any object, change or event if they experience it first-hand (Wenham 2005; Rocard & Csemely et al., 2007). Wenham (2005), however, points out that primary teachers, who give practical work are often not focused on understanding at a more abstract level. The focus of these teachers is on the facts; not on exploring ideas or concepts or developing explanations with their pupils. Even if pupils and primary teachers are not able to grasp every concept, according to Wenham (2005) it is important that the learning of concepts is, nevertheless, given more attention in education.

Design methodologists, as well as authors in the field of philosophy of technology, emphasize the importance of abstract knowledge in designing and engineering. Various types of conceptual knowledge categories are described in the literature:

- Fundamental design concepts (Vincenti, 1990). These design concepts are 'normal configurations' of a product, e.g. standard images of an end product or a number of existing designs (Broens and De Vries, 2003). They describe the generic idea behind a design.

- Structural rules (Ropohl, 1997). These rules are concerned about the assembly and interplay of the components of a product or technical system.

- Scientific or natural laws (Broens and De Vries, 2003).

- Mathematical models and technological rules (Vincenti, 1990; Broens and De Vries, 2003). Designers apply mathematical methods and theories, formulas for calculations, technological rules and/or rules of the thumb in design processes.

These concepts are used to understand the operation of an existing product. Furthermore, designers use them as heuristics in design processes. Although scientific and technological concepts never dictate a solution, they often guide the search of the designer and point towards specific, promising directions (Kroes, 1995). As educational researchers Cropley and Urban (2000) argue that concepts are a powerful tool in creative problem-solving processes. Naturally, design processes are not always based on explicit concepts. Designers also use trial and error strategies (Vincenti, 1990; Kroes, 1995), engineering experimentation (Vincenti, 1990) or intuitive, tacit knowledge (Polanyi, 1966).

Obviously, abstract knowledge is an important factor in concept learning. However, abstract knowledge is strongly coupled with already earlier mentioned concrete knowledge. Let's explore this aspect bit further. Design methodologists such as Van Aken (2005) and Muller and Thöring (2010) have made taxonomies of knowledge categories used by adult designers and included knowledge about concrete products as a separate category. Van Aken (2005) describes object knowledge as knowledge about the characteristics and properties of artefacts and their materials. Muller and Thöring (2010) call this category 'design artefacts' and describe it as form, gestalt or embodied knowledge. Another term used in the literature is device knowledge (Gott, 1988; Compton, 2004).

However, concrete products offer another, unique dimension to connect social context and concepts. This approach originates from their dual nature. Products have a physical and their intentional (functional) nature (Kroes, 2002; De Vries, 2005; Kroes & Meijers, 2006). Products are physical objects that are described by physical properties. However, products function in social contexts and derive their meaning from intentional or functional aspects. For example, a guitar has its physical properties. They are such because of certain scientific laws dictate them to be like that, in order to produce sound. However, what separates a guitar from a violin (or from a drum) is that the physical properties correspond to the type of sound guitars produce. A guitar would not be a guitar if it did not produce a certain sound that was typical for guitars and this way entertain people. An important physical property of a violin is its bow. Thus, would a violin still be a violin without its bow or would it become a guitar?

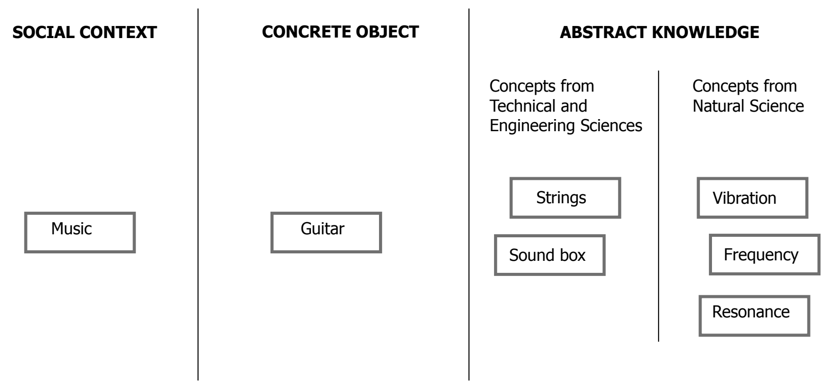
This idea of products having a dual nature makes them interesting for concept-context learning. On one hand they can be brought into a classroom; they can be touched and examined and this way they offer tangible, concrete experiences to the learner. On the other hand, they have their functional nature and these same products connect the concept (theory) to its context (practice). The physical properties of a product gain their meaning through the functional aspect, an ideal approach for concept-context learning. Thus, the theory is explained by using and seeing an artefact functioning in its surroundings, in its context.

Thus, based on the literature described above, closer attention is required to the way abstract and practical knowledge should be combined to support concept learning in real-life situations. This should be done by using the dual nature of products. Most authors emphasise only two knowledge domains (asking what and why –questions refers to combining concrete object and abstract knowledge, and concept-context approach teaches concepts in different (social) settings), but the literature study revealed that three domains need attention; social context plays an important role as well.

To answer to the above the three-domain model that supports both the design process as well as concept learning is introduced. The model visualizes important factors in the design process and describes how to emphasise teaching and learning of concepts in specific contexts. The model is a knowledge-theoretical model and it does not address the issue of how the educational settings, where it is used, need to be arranged. The idea of the model is to conceptualise and represent an answer to the discovered issues in concept-context learning. The model recognizes three knowledge domains but the way these three domains are incorporated in to a lesson, is left up to the user. With the term 'movement', the non-linearity of the model is emphasized. The 'starting point' can be either the social context domain or the concrete object or abstract knowledge domain, as will be later demonstrated in this manuscript. What the model conceptualizes is that all these domains need to be included into concept learning by moving between and through each of them.

In the first part of the model, the learning process has been divided into three domains; social context, concrete object and abstract knowledge (Figure 9). These domains are knowledge domains and therefore, describe the knowledge of social context, the knowledge of concrete objects and the knowledge of theory-related concepts (abstract knowledge). The first domain provides the social context for learning. The next domain is about concrete objects, where the information about a specific object or a product is gathered and examined. In the third domain, the information is deepened with abstract knowledge. This level contains concepts from technical and

Figure 9. Three domain model for concept learning with music as an example.



engineering sciences. Concepts from natural science are even more abstract.

In the first domain the learner is confronted with real-life problems, e.g. a broken music instrument. The social domain provides the right context to intrigue and trigger the learner into studying the social context, concrete objects and concepts. This domain can be compared Vygotsky's social context. Including this domain in educational situations also responds to the requirements of (adult) learners, described by Andragogy (Knowles et al., 2011). According to Andragogy, adults need an orientation to learning, which means that adults are motivated to learn when the learning will help them to perform tasks or deal with situations that they confront in their life situations (Knowles et al., 2011). Thus, adults learn new knowledge most effectively when this new understanding or a skill is presented in a context of real-life situation (Knowles et al., 2011).

In the domain of concrete objects the learner is confronted with objects such as products, materials, tools and hands-on experiments. Here, as in Levin's action research model, the here-and-now concrete experience is important (Kolb, 1984). The learner faces a concrete thing or collects factual information from experiments. Relevant elements, such as the strings or the specific shape of the sound box of a guitar, need to be identified. The position of concrete object in the middle of the model is not arbitrary. The artefacts have a core role in this model because of their dual nature.

In the next, abstract knowledge domain, the explanations and the relevant concepts are explored. The conceptual knowledge obtained can be technical or scientific. With this obtained knowledge, learners can choose a better approach for a further exploration of objects or develop an alternative, improved object, e.g. an enhanced string instrument.

Each domain enriches and inspires the learning in the other domains. This enrichment should happen until the task is finished. Learning should not take place in a pipeline from context to theory; learning in one domain is connected in various ways to the learning in the other domains.

A similar approach has been described by Verillon and Rabardel (1995). Their model is called the Instrumented Activity Situation (IAS) -model. They, as well as the study here, found bipolar models insufficient and wanted to highlight the importance and more importantly, intermediary status of concrete object. The IAS-model binds together three characteristics; subject, instrument and object as well as multiple relationships between these characteristics (Verillo & Rabardel, 1995). The best way to describe the idea behind the IAS-model is to use the same example of baby learning how to use a spoon by Verillo and Rabardel (1995).

> *"Not only does he have to elaborate efficient schemes in order to grasp and manipulate the spoon (subject-instrument interaction), but he has to learn to keep some of the milk in the spoon on the way to his mouth instrument-object interaction). In the process of this, he acquires some knowledge about the behaviour of the liquids as opposed, say, to mashed potatoes (subject-object interaction mediated by the instrument)."*

5.3. Examples from research on concepts related to air and water

In this section, the model is used to reflect on how in-service teachers learned concepts related to air and water. The examples are taken from the same data as presented in Chapter 2 but now the data are looked from a different angle and the interpretation is new. Here, instead of analysing teachers' concept learning, the purpose is to show how insight of the three domains and their connections can be used to improve teaching and learning process. The model is used to explain educational situations and how the approach could be altered with the help of the model to address the needs of the learners better.

5.3.1. Dealing with confusion

The first example is a comparison of two questions. In the first question the teachers (see Chapter 2 for full description of the teachers) were asked to compare the weight of two glass bottles, one filled with air, the other one made a vacuum. This question aimed at testing if the teachers understand the concept of mass of air. The second question asked if it is possible to pump air into a swim ring that has five books on top of it. The concept tested force of air. In the table below (Table 7), the types of answers from teachers to both questions are presented.

In the answers to the first question, more than half of the teachers (A, B and C) stated that adding or removing air from the bottle does not change the weight. Given the replies, it seems as if air is believed to be weightless. When compared to the answers about the force of air, the confusion of the characteristics of air can be observed. In the answers, such as given by Teacher D, air was stated to be nothing; however, it could lift the books. Similar results have been reported by Rollnick and Rutherford (1990), where pre-service teachers' answers about air and air pressure contradict the scientific concepts.

The above presented confusion indicates that the

Table 7. Comparison of two questions about air.

Teacher	Answer to Q1: GLASS BOTTLES	Answers to Q2: SWIM RING
A	Answers such as *"Air is something, but it has no influence on the weight."*	*"Yes, the air goes into the ring and everything is lifted."*
B	(same as above)	*"Yes, the band becomes firm."*
C	(same as above)	*"Yes, that is possible because the increase of air makes the ring thicker."*
D	Answers such as *"Air is nothing."*	*"The books will rise if you put enough air in. The mass of the air is more than the books."*

theories are learned as detached units. The universal use (Yin et al. 2008) of a theory is hampered due to the isolation of the theory from its applications and the situations in which to use it. The offered aid by the three-domain model is that a theory (abstract knowledge domain) supports the understanding of an experiment (concrete object domain) and, as a feedback, experiments support the more universal understanding of that theory. Since a more practical example triggered correct answers, experiments should be connected to the social context domain to have a direction in the learning. The cycles made between the domains, attach understanding to a theory and meaning to an experiment.

5.3.2. Making the knowledge more accessible

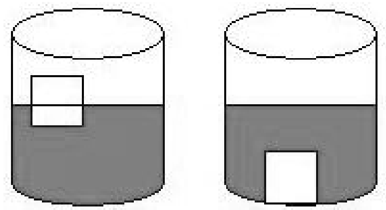
Two teachers answered to both pre- and post-training assignments (see Chapter 2). In both cases teachers were asked why an ice cube floats in one glass and why it sinks to the bottom in the other glass (concept of density). Both of the ice cubes are placed in two identical glasses and the cubes themselves are identical as well (by means of weight and size).

In the pre-lesson assignment, the above picture was given (Figure 10). In the post-lesson assignment, the same situation was explained by written text. It was added to the question that one glass was filled with water and the other one with alcohol. In both cases teachers were asked to explain why one cube floats and the other one sinks (Table 8).

In both answers, it can be seen that the investigation process is somehow inadequate and the meaning of density is wrongly understood. In the case of Teacher A, a more practical idea of what makes an ice cube float has changed into scientific explanation, a wrong one though. Teacher B has an idea of density before the training takes place, even though the term itself is not used. But after the training, like Teacher A, the concept has changed into a wrong answer. This

Figure 10. Identical ice cubes in different liquids.

Table 8. Comparison of pre- and post-lesson answers of two teachers.



Teacher	PRE-LESSON	POST-LESSON
A	*"In the one block there is more air?? That's why it floats."*	*"The density of alcohol is bigger than water's."*
B	*"The liquid is from another kind (e.g. salt or soup)."*	*"It is a matter of another density; in ice the molecules are closer to each other than in the water around them. In alcohol this is not the case. "*

contradicts with the study of Loverude et al. (2003), where the students explained floating correctly in terms of lower density.

Here a new, wrong interpretation of the theory can be seen. To avoid this, based on the three-domain model, the new information is related to what is already known about the topic (evaluation) and therefore, better questions can be asked; namely questions aiming towards a better explanation.

The answers also show how obtained knowledge becomes isolated and meaningless, especially if the experiments support trial-error type of learning or if they are rushed through. With the movements in the model, the relationship between the theory and practice becomes more evident and the explanation is better connected to the experiment. In the course of this, more reflection is included to learning and therefore, the learning process becomes more critical. If a critical comparison and reflection to the previous knowledge happens, the learner is able to notice "the lack of logic" in the thinking.

5.3.3. Obtaining usable knowledge

In the last example, teachers were asked what makes the first balloon stay put and the other balloon rise (Figure 11).

The concept examined here was density. In one third of the given answers the term was used correctly (Teacher A, Table 9). Another third of the teachers (Teacher B) cautiously replied something about lighter weight or heavier gas. For research purposes the last third of the answers form an interesting group. Answers such as those given by Teachers C and D (Table 9) on the special behaviour of gas, show gases

Figure 11. Two balloons with different behaviour.

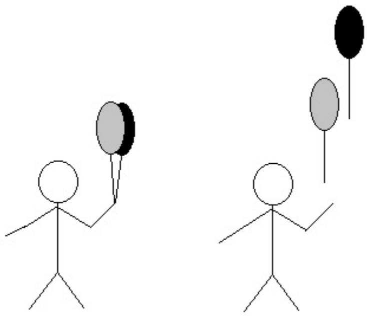


Table 9. Answers to the question about the two balloons.

Teacher	Answers
A	*"In the yellow there is helium and in the red one there is blown air. Helium is lighter than air."*
B	*"The yellow balloon is lighter in terms of weight."*
C	*"Due to the gas the balloon rises."*
D	*"There is probably gas in it."*

being completely different from air. Contradictory results have been reported in Rollnick and Rutherford (1990). Here it is thought that air consists of many gases.

The answers that divided gases into air and other gases are based on a practical way to approach the concept of gas. The explanation could be that in the carnival, balloons are sold and they are filled with gas that comes out of the cylinders. This gas makes the balloons rise and this knowledge is enough in everyday-life. The problem arises when this everyday conceptualization is confronted with the scientific explanation of the same phenomena.
In the model this practical knowledge would be a starting point and the knowledge would be refined into scientific knowledge progressively, while moving between the domains. An idea, even a wrong one, sets a certain goal to what to expect. Hence, the result of an experiment seeks explanation from the abstract knowledge and this is reflected to the original idea. Investigation includes repetition and knowledge that is gradually built and correction of wrong ideas and scientific theories that become more natural to the learner. This does not only help the teachers to see the theories in a more applicable way, but also it introduces a method to teach them to the students and hopefully reassures the teachers to apply more theories.

The model helps to give structure to the teaching and learning. This way, more attention can be focused on detecting scientifically false ideas and on to the process of moving away from them. Iterations between the three domains offer an approach, whereby knowledge is obtained based on the learner's needs. A movement further away from the impression that the teacher in front of the classroom provides all the information can be accomplished by using the model.

5.4. Example from research on creativity

In this section, the model is employed to understand how the three domains are used in the development of creative, socially relevant design solutions. The data are collected by and belongs to Dr. Remke Klapwijk. The following example is used in this dissertation to deepen the analysis of the model.

The selected social context in one of the training sessions was a flying contest. Participants were asked to design and test a paper airplane that is either very fast, stays very long in the air or flies in a funny way. A short description of how to build three different models was provided and the in-service teachers were asked 'to adapt these examples to make them better'. Trainers gave examples of elements that could be changed in the design, e.g. use of different material or bigger plane. Earlier, concept cartoons and practical experiments with air were used to learn about related concepts e.g. air is something, air has force, the Bernoulli principle and wing shape. Two examples from the training are given below. In both of them the focus is only on the concrete object domain and the abstract domain is neglected.

> Primary school Teacher D tosses a paper airplane. The first time it covers a short distance and the second time it reaches the other side of the classroom.
>
> Trainer: "*This is better*."

D nods and tells: “*The previous time, the plane reached the blackboard, the plane is able to cover a larger distance …*“

Trainer: ”*Ah.*”

D: “*The plane is thus better than we just saw.*”

In the discussion, causal explanations and why questions are nonexistent. The testing and evaluation of the planes was mainly used to check facts. The teachers focused on finding out which plane flies the longest distance, but the trainers did not encourage the teachers to explore and understand why one covers a longer distance than another plane. However, there were a few exceptions. In each course one of the participants started to connect the abstract and the concrete domain, e.g. Teacher C describes what was happening in factual terms and provided a causal explanation.

Teacher B has made a very large NASA airplane (see Picture 4) from paper.

Teacher A calls: “*Throw it to me!*”

B throws the large NASA airplane.

Teacher A shouts with joy: “*Yes!*”

Teacher C, holding a smaller model of the same NASA plane in her hand, is watching.

C: “*This is really strange. It is different when I do it, when you throw the plane one of the loops is at the other side.*”

B throws the large NASA model again.

B says: “*Yes, this is because the loop is ‘floppy’.*”

C: “*When the model flies, that one loop is below the straw*.”

The teachers throw the model again.

C: “*Yes, the loop falls down, but the air pressure makes it rise again. You can see a sort of rotation.*”

Picture 4. Unconventional NASA airplane (Source: http://quest.arc.nasa.gov/aero/teachers/ia3.html)

Although some of the scientific explanations of the behaviour of paper airplanes can be hard to grasp, a number of generalizations can be understood by primary teachers. They could learn during the experiments that the behaviour of the plane is not determined by just one element or concept. The lucky throw example shows the influence of the throwing behaviour and trainers could refer to a number of optimal throwing strategies described e.g. on the Internet.

Concrete product information (form, materials, size) should be related to concepts during the product evaluation. References to the concepts that were central in prior activities in the training (concept cartoon discussions and practical experiments) should be stimulated. During the design process, trainers could challenge participants to develop and list concepts that they think will be helpful in explaining the behaviour, such as the rotation point of the plane. Learners may be able to develop a few generalizations from the testing part of the design cycle.

In this way, design experiments are used to understand concepts in a specific context. A why-focused evaluation may enhance creativity and innovation. Although causal explanations do not tell exactly what one needs to do differently, they help to find plausible directions to search for alternative designs. Evaluation should be about the value of the designed products to us. During the training, the need to cover a long distance was, however, in the limelight, whereas social needs such as staying long in the air and funny flying were neglected. As a result the learning process was not (re)directed through evaluation in the sense of what needs to be done and why it needs to be done. Focusing on social needs will stimulate a more varied production of airplanes at the concrete domain and lead to a deeper conceptual understanding. Goals from the social domain will motivate learners to explore the concrete and abstract domain (Bennett et al., 2006).

The training session on flying included the three different domains but this is not enough. The domains need to be connected in the learning activities to arrive at the effective concept learning and successful design outcomes. Linking of domains should be repeated in a continuous movement and the design process provides ample opportunities to connect all three domains.

5.5. Discussion

The literature study indicates the importance of paying attention to three domains, the social, the concrete and the abstract. The examples from the in-service teacher training show that it is not enough to include each of the three domains individually. Connecting these domains is just as essential and should be repeated.

The approach improves concept learning and these concepts provide additional heuristic strategies for the development of creative designs. In a rough sense, social context provides the beginning input for the learning process, but in this model the intention of is to be present throughout the learning process, giving it direction. Movement between the first-hand experiences with concrete products and processes and the concepts is part of the model. This involves, amongst other activities, the exploration of theories and concepts that explain the concrete experiences or that are fruitful heuristics in concrete design activities.

What can be difficult in concept education is to stop the process when students are creating, but moving away from the original assignment. Teachers may think that as long as the learners are designing and developing, everything is on track. In the end this might lead to creative, innovative products and designs but they are not an answer to the original question. This is not necessarily a bad outcome, but with the model this messiness and uncertainty of the topic can be safely included in a learning process due to the 'checks', when moving between the domains. The model allows the exploration of possible wrong paths and this way an opportunity of getting acquainted with the fuzziness of science and technology but at the same time the process is kept under control with constant reflection on the previous activity but equally on the following one.

In any design assignment more than one technological or scientific concept is needed to execute the design process. This requires knowledge from many different concepts, some of them relatively unknown or difficult to the learner. This asks for a flexible use of knowledge of concepts that many trainers regard as above their expertise. This might be a reason why trainers avoid any type of open design assignment or tend to neglect the fact that they have to focus on conceptual knowledge in design processes. However, science and technology education has a good opportunity to introduce learning that happens gradually. With the help of the model the learner builds the knowledge as the process goes on. Therefore, a teacher does not have to have all the answers at hand. The purpose of science and technology education should be to prepare the learner for functioning in a society, in which new technologies and applications keep on emerging with increasing speed. Science and technology education should be about getting away from learning just formulas and theories. The focus should be on providing education in such a way that this ability is given time to develop and become part of the natural way of thinking. Focusing on one concept, as Crismond (2001) proposes, might be a solution, but then the natural characteristics of science and technology being a messy topic, disappears.

One type of disorder in learning a concept is in place. Science with its theories and technology with its applications are complicated and therefore, they should be allowed to be learned as such. One concept is more important and influential in one phase and later, e.g. when finalizing the design or product, understanding of another concept becomes more critical. However, this approach should not be mixed with isolating one concept. Sometimes it is important to know which concept needs the most attention among many concepts to be mastered. Learning to apply new knowledge and expand existing ones, is applying science and technology into practice, into everyday-life.

5.6. Conclusion

Better use of practical work on artefacts is likely to benefit concept learning. In current concept learning, practical work on artefacts is often not optimally used or meaningful for the learning of concepts. The model, presented in this chapter, takes the dual nature of products into account as well as the need to relate practical, concrete experiences to abstract, causal explanations.

One may use the model to analyze existing situations and to develop new trainings that have:

1) A better balance between the three knowledge domains,

2) Many iterative connections between the domains, and

3) Regular checks when moving from one domain to another.

The three knowledge domains were present in the professional training for primary in-service teachers and in some cases effectively connected. However, based on the analysis and the comparison to the three domain model, shortcomings were revealed. The connection between the theory, concrete experiences and the social context need to be more visible and inviting.

By knowing that the teachers have a tendency to go back to practical explanations and avoid scientific explanations, trainers need to get frequent information about unclear parts so that it is constantly visible when something goes wrong with the abstract reasoning.

Furthermore, the analysis showed that existing 'misconceptions' were often ignored in the training. As a result, these concepts tend to appear again in other contexts or they are combined with the newly provided theoretical information into a new 'misconception'. It is suggested to use the existing common ideas, 'misconceptions' and practical explanations of the learners as a starting point for teaching and learning.

The analysis also showed how useful connections between the three domains can be realized. Product-evaluation focuses often only on the concrete domain, but this is also a good 'location' to connect all the three domains. Approaching the evaluation from specific actor needs stimulates in-depth learning and creativity.

Iterative connections are needed to develop an in-depth understanding of the concepts. Usually different concepts are needed to develop a holistic, in-depth understanding of a specific product. Hence, trainers need to be aware of this complex nature of concept learning.

The three domain model is useful in understanding how concepts are related to real-life contexts and to improve the effectiveness of concept learning. It emphasizes the importance of moving between knowledge domains and paying attention to connections.

Based on this empirical study, the three-domain model proves to be useful in understanding how concepts are related to real-life contexts and in how to improve the effectiveness of concept learning. It emphasizes the importance of moving between knowledge domains and of paying attention to connections. In the next chapter, a preliminary test is performed to see if the ideas are correct and applicable to a classroom environment.

Chapter six

6. Testing the usability of the model [22]

6.1. Introduction

Suc·cess·ful execution of a lesson using the model will provide an evidence that the knowledge model works in practice. The previous chapter presented the theory behind this model and now this chapter will move on to present a pilot test of the model. Helping teachers to move away from linear approach to teaching, encouraging them to collect knowledge together with their students as well as providing them support to do this are the fundamental issues that this chapter wants to explore.The three-domain model suggests that while teaching science and technology lessons, teachers might benefit from paying more attention to three domains; social context, concrete object and abstract knowledge, and furthermore, constantly move between these. Although the three-domain model is based on real teaching situations, it is not self-evident that the model can be used as such in practice.

The model can be combined with different pedagogical strategies in teaching. For instance, relations between the knowledge can be introduced in different orders, depending, for instance, on the level of education. This chapter does not test what pedagogical strategy works the best. Instead it will seek for an evidence of the existence of feasible combinations of the model and a pedagogical strategy. This is done by showing that at least one such combination can be shown to work for at least one teacher. For this purpose, again, a qualitative research is appropriate.

Two teachers tested the model in their classrooms in order to see if the model helps them in planning a lesson, and if the teachers (and their students) benefit from the approach. The analysis is based on the pre- and post-lesson discussions with the teachers, lesson plans made by the teachers and observations made during the lesson. Analysis revealed that the model helped the teachers to seek for opportunities for the students to communicate their understanding. The teachers kept on looking for appropriate moments to bring more insight

22 Based on: Koski, M-I., & Vries, M. J. de. An aid for teachers to teach science and technology concepts - two case studies to test the three-domain model. *International Journal of Technology and Design Education* (accepted).

to the topic and they would have missed those moments without thinking in terms of the model. The use of the model also introduced them to a non-linear teaching method and the profit of applying such. The study concludes that both teachers benefited from using the model in their preparation of the lesson as well as during the lesson.

The chapter begins by presenting a literature review on issues in teachers' professional learning (section 6.2). In section 6.3 the reasons why to use the model to plan a lesson are given. Design of the study is presented in section Design of the study 6.4. Furthermore, the preparations prior to the teachers using the model are explained in section 6.5. The two successful lessons that applied the model in practice are shown in section 6.6. One example (sub-section 6.6.1) is from a student teacher wanting to increase creativity and group work in her classroom. The other example (sub-section 6.6.2) is from an experienced teacher attempting to include theory of structures to a design class with young pupils. Sub-section 6.6.3 presents a separate evaluation of the model by the experienced teacher. Section 6.7 discusses the findings and the limitations of the study as well as gives future recommendations. In section 6.8 a conclusion is made.

6.2. Teachers' professional learning

In order to get an idea what is expected from teachers' professional learning, a literature study was conducted. After exploring the general thoughts and suggestions, more specific issues in teachers' professional development activities in science and technology education are discussed.

Teachers learn and develop their skills during their professional career. Schools they work in and the colleagues they work with can influence this greatly. The complex dynamics and features in school culture as well as history and policies have an effect on teachers' professional learning (Jurasaite-Harbison & Rex, 2010).

Many of the learning opportunities offered to teachers have failed (Donovan, Bransford & Pellegrino, 1999). However, Donovan et al. (1999) go on to point out that there are also successful examples that seem to fulfil these requirements rather well. Often the problem with the professional training is that it lasts for a short period of time and the opportunity for a lifelong professional development is in the hands of each individual teacher. According to Jurasaita-Harbison and Rex (2010) in order to accomplish lifelong professional development it is crucial to acknowledge the importance of informal learning. Therefore, instead of providing special skills or pure subject knowledge, the professional training should emphasize skills that would help teachers to look for and acquire knowledge themselves. Penuel, Gallagher and Moorthny (2011) argue among others that it is important to support teachers to develop the capacity to design sequences of instruction that are based on pedagogical principles.

However, often the suggested improvements are too abstract for the teachers and students to apply in their daily practice. Paavola and Hakkarainen (2005) address three issues of learning in their article. The authors review the relationship of three methodologies of learning: knowledge acquisition, participation and as a new dimension, knowledge-creation. This new dimension addresses "collaborative, systematic development of common objects in activity" (Paavola & Hakkarainen, 2005). These three approaches reveal interesting ideas about learning and cognition. Furthermore, Paavola and Hakkarainen (2005) present schools as knowledge-creating organizations and encourage teachers to share their professional experiences within and between schools. Unfortunately, applying the actual suggestion in practice seems rather challenging.

Boulton-Lewis (1994) points out that despite the large amount of research done in the process of learning, the results do not reach the educational practice. It appears that the issues have been there for a long time before Boulton-Lewis brought it up and they seem to remain. For example Chikasandra, Ortel-Cass, Williams and Jones (2013) report on a professional development activity designed to enhance teachers' knowledge of the nature of technology and technological pedagogical practices. The analysis showed that teachers' knowledge of technology had improved, however, the technological pedagogical techniques that they used corresponded to traditional strategies for teaching technical subjects (Chikasandra et al., 2013).

Suggestions in the field of technology education range from an open-ended design challenge to a structured, lengthy curriculum program (Zubrowski, 2002). According to Zubrowski (2002), one of the problems that technology education suffers from is that these improvements lack depth. On the other hand, educational research appears to offer too abstract solutions to improve teaching and learning.

The professional training activities for science and technology teachers should focus on teachers' understanding of science but also to the ways this understanding can be applied into classroom practice (Lederman, 1999). The teachers should be provided with tools to reflect their teaching. It is necessary to suggest improvements that can be applied into classroom practice with a relatively small amount of effort. Besides being easy to adapt, the improvements need to provide an aid that does not depend on context or subject but instead provides help in thinking and planning the lessons. There is a need for a model or a product that brings critical thinking (Zubrowski, 2002) into the process as well.

This same line of thought is reported in two studies, to name a few. Gerard, Varma, Corliss and Linn (2011) conclude that professional development programs that support teachers to engage in comprehensive, constructivist-orientated learning processes can improve students' inquiry science learning. They emphasize that the key is to guide teachers to elicit, add, distinguish, reflect and integrate ideas (Gerard et al., 2011) and this way the teachers learn to support students' inquiry science learning. Daugherty and Custer (2012) point out that in secondary level engineering professional development the conceptual foundation of engineering education was not clearly formulated for the teachers to use. The researchers noted the development activities emphasised modelling and applied learning at the expense of reflection and analysis of the pedagogical processes and techniques (Daugherty & Custer, 2012).

Penuel, Gallagher and Moorthy (2011) point out that the most effective ways to improve students' (science) learning is to offer explicit instruction of the models of teaching to the teachers. Here, it is assumed that the three-domain model can be seen as one of the models of teaching. In the light of that assumption, the recommendations (e.g. Lederman, 1999) and the findings of the two studies (Gerard et al., 2011; Daugherty & Custer, 2012), the three-domain model offers an interesting approach to investigate. The three-domain model seems to support informal learning, comprehensive and constructivist-orientated learning, analysis of the teaching processes as well as reflection; the important aspects of teachers' professional learning listed in the other studies.

6.3. Reasons to use the model to plan a lesson

Issues, such as why students still graduate with superficial knowledge, do not only appear because of students not knowing how to learn or their lacking motivation. These issues could be a result of teachers' knowledge level, different expectations, strategies or course organization (Boulton-Lewis, 1994). There is a need for an aid to help teachers rethink their subject knowledge as well as their teaching methodology (Donovan et al., 1999). The three-domain model (from now on the model) offers an answer to this need. It describes a teaching approach that shows how to connect concrete objects with relevant theory in a social context that students are familiar with (see previous chapter). This approach offers a chance to gain more subject matter knowledge as well.

The model takes a more research-oriented approach to designing a lesson. Korthagen, Loughran and Russell (2006) explain that teachers benefit from having a research-oriented mindset and they need to be capable of directing their professional development by doing their own research. The model does not require every teacher to behave like a researcher. It encourages collecting and combining knowledge in a same manner as a researcher would do. This way knowledge is created for a purpose and it is more meaningful to the learner, whether it is the teacher or the students (Korthagen et al., 2006).

The model introduces a teaching method that is not linear. This approach asks for an adjustment in teacher's normal approach because teachers have a tendency to describe knowledge construction as a linear process (Gomez-Zwiep, 2008). The idea is that throughout the learning process, teachers would provide information to their pupils so that knowledge is built together with the experience at hand. To gain the biggest benefit, appropriate information must be available during the ongoing situation of comprehension (Bransford & Johnson, 1972). Therefore, knowledge will be constructed according to the needs at a certain moment in learning.

The benefit of using the model is that teachers reflect their teaching to the response from the classroom. In her study Gomez-Zwiep (2008) found out that teachers do not consider that misconceptions are tied to the broader understanding and knowledge that the students have. Teachers tend to start with the knowledge that pupils have and think that after instruction additional knowledge is built on it (Gomez-Zwiep, 2008). However, for learning to happen students need to be able to communicate their evolving understanding and space for communication needs to be provided in the lesson planning (Spektor-Levy, Eylon & Scherz, 2009). By switching between the different domains of the model, assignments are not executed one after the other; they rather support each other. Knowledge is built through communication and by combining different types of information.

With the approach of moving between the domains and linking the information, teacher receives information on whether the obtained knowledge is sufficient to move on with the project or does something need more explaining. Often teachers move ahead in their instruction without reflecting on the evidence they have about their pupils' knowledge (Gomez-Zwiep, 2008). In order to adapt the next move or approach to the knowledge level of the pupils, the teacher needs to reflect on what has been taught and how the pupils have responded to it. As the model emphasizes the constant movement between the domains, the teacher is aware of the fact that sometimes they need to go back and explain something again. Without this thought in mind, the uncertain situations may slip away without proper response.

The model offers structure to the design process. It does not force the process to follow a strict plan but it offers guidance and support. By using the model the teacher keeps track of the topic that needs to be addressed within the (science and) technology or design project. According to Barak (2012) students' creativity and problem solving skills can only slightly benefit from providing students with inventive problem-solving principles and pre-designed exercises. Teaching principles without applying them and limiting a design exercise to a pre-agreed model does not sound like an ideal design education. However, engaging students in a project that has an open end asks a lot from the teacher as well as from the students. Often in the hands of not so experienced teachers these projects turn into just doing something and the original goal of the project is forgotten. Teachers, who endorse the use of hands-on activities, may not consider how their pupils interpret the experience, or if the experience will meet the teacher's instructional expectations (Gomez-Zwiep, 2008). The younger the pupils are, the more important it is to have a plan and keep the end goal in mind at all times. Having open-ended projects is great for creativity but both students and teacher need to be experienced designers in order to fully benefit from them. In the end, at schools every project has a learning goal that needs to be fulfilled.

6.4. Design of the study

In order to examine if the model can meet its expectations, this study was organized. A question directed the design and execution of the study:

> Is there a feasible setup for a knowledge model so that concept learning of science and technology is enhanced?

To answer the question teachers were invited to use the model to plan a lesson. Due to reasons explained in the following section, the design of the study had to be adjusted to follow only two teachers. In Figure 12 this adjusted design of the study is presented. The fact that two teachers participated in to this study divided the data in to two sub-studies; one with a student teacher and the other one with an experienced teacher (see Figure 12). Both of the studies were, like all the other studies presented in this dissertation, qualitative in nature.

Firstly, the author gave a presentation at an in-service teacher training (see more in 6.5.1). The student teacher did not participate in the in-service teacher training and the study had to deviate from the original plan again. This will also be discussed later. The lesson planning phase included the actual plan of the 'model lessons' as well as the discussions of the goals for these lessons. After this the teachers gave their lessons and later on an evaluation followed. The analysed data included evaluations between the author and the teachers (see for the guiding questions for the evaluation), plus the lesson plans, observation and videos from the lessons. All of these phases are included to the results of the usability of the model in primary science and technology education. A similar design and approach to perform teachers' professional development case study is presented in Capo (2013).

This study was qualitative in its nature. It followed the description of qualitative study by Henn, Weinstein and Foard (2008) by being a small-scale but detailed and rather intensive study. The chosen method was used to construct an understanding of the usability of the model in classroom environment. Another interesting way to investigate the use of the model would have been to compare the approaches between the experienced teacher the student teacher. However, as this study was the first attempt to see if the model can be used in primary science and technology education, the emphasis was on how to the teachers use the model to plan and execute the lessons with the help of the model. The study focused on finding the movements between the domains and observing the responses both the student and the teacher had to the approach. The lessons were recorded and these videos came in need, since some of the results could not be understood by simply viewing the answers.

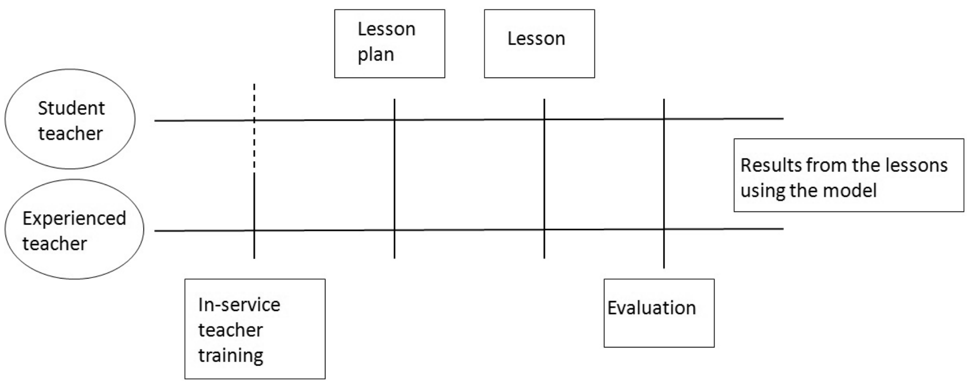
6.5. Preparations prior to teachers using the model

6.5.1. A presentation in a workshop for in-service teachers

The author gave a presentation about the model in an in-service teacher training workshop. This workshop took place in January 2012. In the workshop the total time reserved for the presentation was 30 minutes with a question and answer session at the end. In the presentation the author showed how to prepare a lesson with the help of the model and how to apply it during a lesson. The presentation did not include any theory; it focused on giving a practical, ready-to-use example of the model to the participating teachers.

Before preparing the actual presentation the author had a discussion with two of the organizers of the

Figure 12. Design of the study.



workshop. In this discussion the basic idea of the model was explained to the organizers. After this it was decided that the best approach to explain the model to the teachers was to prepare an imaginary lesson using the model. The 'topic' of this lesson was decided together with the organizer; namely how to build a tin-can telephone. The organizers wished that the presentation would use PowerPoint Presentation –program so that the slides can be handed to the teachers later on.

In the presentation, the author showed the exact steps that she would take if she was to prepare such a lesson. At this point, an example will clarify what is meant by this. All the concepts where presented under a social context of communicating between two tree huts. One of the noteworthy concepts for an optimal tin-can telephone is vibration. Vibration plays an important role when a person speaks into one of the two ends of the telephone. For optimal vibration two things need to be considered, 1) what material is used for the cans, and 2) what type of string to use to connect the cans. During the investigation, the author learned that the most optimal material for the cans is (surprisingly) paper, and sewing thread is the best material for the line between the two cans. Why paper as a material is better than metal and why sewing thread is the best, lead to another unknown concept; namely conversion.

After the concept of vibration was tackled, the presentation continued to explore the concept of conversion in a similar manner. The presentation showed how the movements between the domains happened. Solving a problem concerned with a concept (vibration) lead to a problem of concrete materials (cans and threads), and this again lead to an investigation of another concept. Each of the concepts that came along in the research process were presented to and discussed with the teachers. The idea was to make the model explicit to the teachers by showing the information collection and the problem solving steps within the model. The presentation did not take in to consideration the questions from the pupils. But the point was to show the in-service teachers how to prepare a lesson with the help of the model and how it can provide help during the lesson.

The teachers that participated in the workshop came from schools that had received money from the Dutch government to improve technology or creative teaching in their schools. This meant that the schools had agreed to work with a university. The university offered them the training and in return the researcher(s) could conduct research in these schools in collaboration with the teachers.

After the workshop, the author was coupled with one of these schools. In this school seven teachers would use the model. The teachers assured the author that they are interested in working with her and that they have understood what they need to do and how the model works. After the first three lessons that the author followed in the school, it became clear that this was not the case. The teachers were in the background and the responsibility of the lesson was given to a student. This student was appointed there by the workshop organizers to observe the results of the in-service training and to be an assistant to the teacher if required. The problem was communicated to the teachers of the school by the author, the student and the organizers. However, no change occurred. Therefore, it was decided to stop the collaboration with that school.

6.5.2. The student teacher

In March 2012, the author was contacted by a student teacher who had found the model in one blog designed for in-service teachers as a source of inspiration. The student teacher had made a career change; after about ten years in industry she wanted to become a teacher. Next month, the author and the student teacher met to discuss the model and exchange ideas about a feasible lesson plan. In the first meeting, the author explained the parts of the model that were still unclear to the student teacher. This was done by using similar examples as in the workshop earlier that year. The student teacher explained that she wanted to use the model to plan a series of lessons as her final work to graduate as a teacher. In the second meeting a more detailed lesson plan was discussed and several ideas were explored.

Although the student teacher had made lesson plans for each lesson, after every lesson the author and the student teacher exchanged opinions. Before a lesson the teacher would send a lesson plan to the author to get acquainted with. The plan was modified from the original based on the progress of the students and the discussion with the author.

After all the lessons, the co-operation was evaluated. A face-to-face discussion with the student teacher would have been preferred. However, due to the limited amount of available time, the evaluation was done via emails and phone calls. Because of the close relationship that the teacher and the author had formed, phone calls and emails served the purpose well.

6.5.3. The experienced teacher

The experienced teacher participated in a workshop where the author gave a presentation. In April 2012 the author contacted the teacher to ask her if she wanted to participate in this study as well. The teacher expressed her interest in using the model in one of her lessons. However, due to the fact that school year was about to end, the actual study was planned to take place after the summer holidays.

In the beginning of the next school year, the author and the teacher exchanged emails to discuss the topic of the lesson. They also had a meeting where the outline of the lesson was discussed. In this meeting the author provided the journal article and the presentation of the model to the teacher. However, it appeared that the teacher did not need them and had understood the idea based on the presentation. The lesson took place in October 2012, and after it the author and the teacher sat down for an evaluation.

6.6. Findings

In the following sub-sections, the results of the data collection are presented. All the lessons included in this study were filmed and after each lesson an evaluation was done. The video recordings were used to validate what happened during the lesson and also from them the transcripts were extracted. The point is to show how the model was applied by the two teachers. The lessons of these two teachers are the two studies presented. The results are reflected on some of the issues raised by other researchers as well.

6.6.1. Testing the model with the student teacher

The model was first tested with a student teacher. She taught her lessons in class with 27 students, age between 11 and 12 years. The study was conducted in a catholic primary school in the Netherlands. The model was first tested with a student teacher. She taught her lessons in class with 27 students, age between 11 and 12 years. The study was conducted in a catholic primary school in the Netherlands. The school where she worked was a 'standard' school, without many technological advantages, and it was located outside of a big city in the Netherlands in a quite suburb area. The parents could easily come and pick up their kids to go home for lunch between the lessons.

The classroom where she taught was too small for such a big group of students. When the students started to build the actual design, the classroom had to be rearranged. The separate groups were working too close to each other and this caused some disorder and uneasiness in the students and in the way they worked.

In general, the classroom had no material for this type of lessons. The student teacher and the students collected the material for the lessons by themselves and the student teacher brought the rest of the required equipment from home. The teacher of the class, who was supervising the student teacher's practical training, was unfamiliar with this type of teaching. She was helpful and tried to participate in the teaching as much as possible. This, however, made her 'step on the student teachers toes'. It happened every now and then that the teacher explained something different to the students than what the student teacher had planned to do. Often the student teacher noticed this 'too late', meaning the students were already doing something according to the teacher's advice. When this happened, the student teacher decided that it was pointless to stop the work and the student teacher changed the plans accordingly.

6.6.1.1. Lesson outline

The lesson focused on teaching the different steps of a design cycle. The overall goal was to design and build something that the pupils could take with them to the camp. Furthermore, the lesson covered some basic mathematics as well as a summary on construction basics from the previous year. The lesson had six learning goals. A list of them can be seen below.

1) Experience and understand the different steps of the design process / cycle,
2) Practice working together and use each other's strengths,
3) Refresh memory about construction basics,
4) Stimulate creativity in solving simple construction problems,
5) Practice preparing and giving a short presentation and
6) Think about sustainability and understand their role in a sustainable future

The project spanned over seven lessons (see the list below) from one and a half hour to two hours and they were taught within five days. In the original plan there were only the first five topics. The latter two were added due to the success of the project. The topic of sustainability had to be excluded due to the lack of time. However, the teacher was able to include bits of it in to the lessons.

1) Design process (definition of a problem, analysis, product requirements, design, testing, evaluation and optimization),
2) Brainstorming (divergent and convergent thinking, rules of brainstorming),
3) Product requirements (extra focus),
4) Construction basics (triangle construction, attaching the parts together),
5) Calculation basics (number of parts required to create the designed product),
6) Evaluation of the design and the product, suggestions for improvements and
7) English lesson, an e-mail to the inventor of the machine about the experience of using the machine

In the beginning of the lesson the students were divided into groups in which they worked throughout the whole project. The teacher had assigned each of the students to their groups. She began the introduction to the topic by explaining what is coming (outline of the lessons) and then she introduced the materials that students would use in their designs. She also explained the materials students would use to design the prototypes.

6.6.1.2. The use of the model

After all the lessons, the videos were analyzed and compared to the observations made during the lesson. However, these did not reveal evidence that the model had been used during the lesson. The student teacher showed no clear signs in her teaching or in the discussions with the students. There was no confirmation that she used the movements between the domains to explain or connected the concrete object to the theory when they were talking about, e.g. material choices. Thus, in a search for evidence, the student teacher's evaluation was used to start the analysis.

In her evaluation, the student teacher emphasized that the model provided her with more confidence to give the lessons. She thought that the students benefited from this approach as well. In the phone call that took place between the author and the student teachers, she expressed that she was able to connect the domains and use the model throughout the lesson. The model served as an umbrella over the whole process. It did not only guarantee her the overview of the series of lessons but it also helped her to keep in mind the little things that needed to be addressed. In her evaluation she emphasized that the various topics linked to the social context, the stronger the motivation and level of involvement of the students are.

> *"By using the school camp as a social context, it made it easier to transfer knowledge about very 'dry' topics such as a design cycle. Thanks to the social context, the various topics seemed to make more sense to the students and also raised their level of involvement significantly."*

The student teacher also described that she used the model to design the groundwork for the project.

> *"I used the model to design the groundwork for the project: it helped me to really link the lessons to a social context (school camp) and gave me the idea to also use the production process with the STIXXs machine as another social context (working and creating together). Unfortunately, I was not able to give the lessons on geography and sustainability, but I did prepare them and again used the school camp as the starting point to make the lesson more meaningful for the students. The sustainability lesson was all around the re-use of trash, availability of resources and giving products and materials another life. This then would have been a perfect opportunity to address the very abstract topic of (consumer) choice and the impact every one can have on the environment."*

She used it to prepare the lesson, as a thinking aid to decide the approach most suitable for the topics. She used the model to decide how to break the topic into smaller parts so that she could explain them better to the students. During the phone call she told that the model helped her to see the topic from "*a formula level*", meaning down to the smallest detail.

Based on what she described, a following example from the videos was observed. The STIXXs (Picture 5) that the students used to make the actual design are round, hollow paper sticks made from old newspaper. In the extract below, the student teacher explains the choice of material and quickly explores the topic of sustainability.

> Teacher (T): *As a material we are going to use newspaper and that is one sort of waste. I'm going to show you things that are made from waste. There are many. When something is thrown away, how can you reuse it?* (Shows different products made out of old paper, chair, necklace, art)

This extract shows that despite the fact that the topic of sustainability could not be included to the lessons she tried to teach even a bit of it to the students. Her plan was to address an abstract topic of consumer choices and the impact that everyone can have on the environment. Again, she would use the school camp as a social context to approach the topic.

Overall, this was an example of the student teacher connecting a concrete object with an abstract knowledge that she wanted to add to the discussion. This is one of the cases where the teacher was able to initiate conversations among the pupils with a relatively small input. In general, the students were not afraid to state their opinion and receive feedback. As a whole, the class appeared to be open for discussions and explanations.

As an example of reuse of materials, the student teacher had brought her necklace made out of recycled paper and she passed it around the classroom. Observations of the STIXX sticks and the necklace triggered the students to think about what you can make out of old plastic bottles. With the help of the student teacher they realized that the Havaianas flip flops that the students like to use are made from recycled plastic bottles.

The previous discussions were followed by a brainstorming session where the students were invited to think what activities they could do at the camp. After comparing ideas within the group, the students practiced clustering. They clustered the previously listed activities and selected a cluster that would give them the most ideas for a design. The goal of this exercise was to move from an activity to a product (e.g. an activity could be to sit and a product that comes from it is a chair).

In her evaluation, the teacher pointed out that without having the model in her mind she would have stopped adding knowledge to the phases of designing and exploring. She described that she would have acted more like the students and just accepted where the process was taking them. Now that she was using the model, she still added new information whenever she saw a possibility. Furthermore, she continued that she most likely would have missed those opportunities to include something new without thinking in terms of the model. Now she was constantly looking for appropriate moments to bring more insights to the attention of the pupils and explain better.

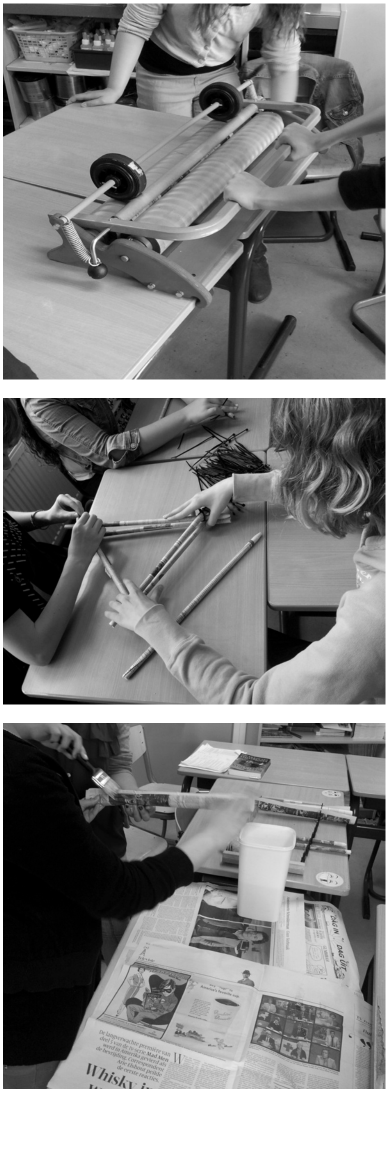
The following extract demonstrates these attempts to add new knowledge to the design process. She wanted the designs to become more accurate. In the extract, the student teacher encouraged the students to express accurate conditions, such as ‘how strong’, ‘how many pieces’, ‘how many kilograms’ and ‘how many meters’ etc. As the students moved away from the activities, their focus was directed more towards the exact product requirements. Each group had their own design idea and they needed to develop it further.

Teacher: “*What other requirements to build a shed can you think of?”*

Student: “*Waterproof*”.

T: “*Yes, that is very important. I’m going to tell you something about this (*shows the material used, STIXX*). It is made out of newspaper and if you throw newspaper or other paper into water it is going to soften (*become into little pieces*). That’s why toilet paper is handy at its use, because when you throw it into the toilet it is going to dissolve. For*

Picture 5. Students making the STIXXS in groups.



newspaper this takes longer but it still happens. Thus, what we are going to do is to spread fiberglass on them, which makes them waterproof. So if you are going to build something for outside, you need to think about making them waterproof as well".

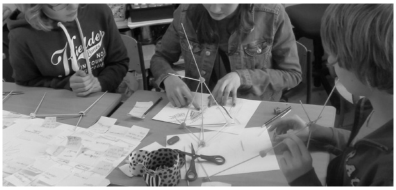
Here, scientific thinking can be observed in a sense of why certain choices need to me made. She explained why making the STIXXs waterproof improves their design. She used the current design of the pupils as a concrete object and added valuable knowledge to it. This all happened within the context of designing but it had the element of sustainability in it as well.

At the end of the first day each group gave a presentation. The requirements for the presentation were to give a name to the design, explain what it is, who is using it and for what it is used during the camp. The presentation had to include three to five the most important product requirements and a prototype as well. In the end everyone voted for the best idea. The result of the voting would determine the design that they would build as a whole class. The winner was a game, invented by one group. In order to play the game students needed to design baskets for point cards.

In her evaluation the student teacher expressed her disappointment with the design project chosen by the students. She was pleased to see the class working on a project together, though. However, with the chosen design (the game) she could not include to the process all the topics she wanted to. She let the students vote for the project and with this she ran the risk of not being able to include everything that she had planned to cover within the project.

Since the issues that rose during the project directed the next steps of the design, the teacher had to re-think the lesson plans after each lesson. She had the overall idea of the project and what topics she wanted to cover, but some minor adjustments needed to be made. According to her evaluation she used the model for these adjustments as well. She evaluated the situation with the help of the model before each new lesson and used the model to choose an approach that was the most useful at the moment. These adjustments were made to address the concrete

Picture 6. Students prototyping based on a chosen design (post-it clusters in the left corner).



problems that the students faced.

The next day the students continued designing the game as a whole class. The day's lesson focused on issues concerning construction. The students needed to think about how many STIXXs they need to have to make all the needed frames for baskets. They also needed to come up with a solution for the handles in the baskets as well as how to cover the frame of the basket in case of rain.

In the evaluation, the teacher described that the model helped her to link the lessons to a social context that was interesting for the students. She explained that thanks to the approach of the model, especially the social context, the various topics seemed to make more sense to the students and also raised their level of involvement significantly. By using the school camp as a social context, it made it easier to explain very dry topics, such as design process and product requirements to the student.

The following extract shows the teacher using the images of where and how the product will be used. This discussion shows how the social context helps to approach concepts. The students started to list more precise product requirements. As one of the main learning goals was to experience and understand the different steps of the design process, the following extract shows the discussion over product requirements (see also Picture 6 and Picture 7).

> Teacher (T): "*Who can name a requirement? What are the requirements for this type of design?*"
>
> Student (S1): "*We need to be able to put them together in a fast and easy way*".
>
> T: "*Ok, that is a good requirement*".
>
> "*Could we make it more specific? What does fast mean? Is three minutes fast? Is an hour fast?*"
>
> S2: "*I think 10 minutes should be enough*".
>
> T: "*That is good. You need to be as precise as possible. When your design is being built and we are putting the pieces together, we need to know whether we have succeeded*".
>
> "*Was it possible to build it in 10 minutes?*"

In the presentations, the students wrote down product requirements such as "*the hut needs to be big*" or "*we need to make it fast*". At that time, the focus was on brainstorming and bringing out the creative design. Now, the task had evolved and the teacher emphasized how important for the whole project it is to determine exact product requirements. After the discussion shown in the above extract, the students started to think in terms of numbers and precise measures. They realized that if the design is not accurate enough the other groups will not be able to produce the same outcome as the designer group had in mind.

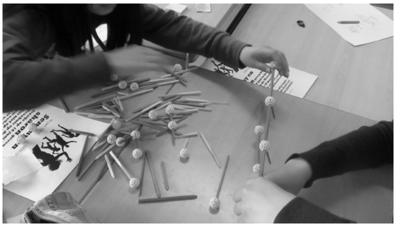
After all the design lessons and the camp, the student teacher held an evaluation lesson, where she asked the students to describe the whole design process. Students described how the product was to use and how they would improve it. Because the product was made to be used during the camp, the students had first-hand experience in how well the product worked and what needed to be improved. The students had several suggestions on what types of improvements were needed. Generally, the student teacher succeeded in showing her students a design process similar to real-life situations and she was able to pin-point the critical phases.

In the future, the student teacher will try to find a social context (or a product) from the students' life to use in the lesson. She also used this project to give a lesson in English. The level of enthusiasm of the students was transferred to this lesson as well and the English lesson turned out to be more effective than the lessons from the text book. The teacher stated that the model brought a new approach to her teaching and she will approach the lessons through the model in the future as well.

6.6.1.3. Co-operation with the student teacher

Similarly to Capobianco (2011) this part of the study could be classified as a collaborative action research, where a university researcher and a future class teacher came together to solve problems, create a different approach to a topic and achieve shared goals regarding teaching and learning. The student teacher wanted to emphasize and make the elements of the design process explicit; just like Zubrowski (2002) suggests technology education should do. The student teacher was interested in researching her own teaching practices, improving her students' learning and seeking an improved understanding of the educational situations happening in the classroom (Feldman & Minstrell, 2000). As close as the working relationship was, both parties had their own responsibilities. The student teacher planned the lessons and wrote a detailed description of them for both, student teacher and the author, to look at and discuss. Furthermore, she arranged the materials as well. The author explained the model to the teacher, discussed about the execution plan of the lesson and conducted the classroom observations.

Picture 7. An early phase prototype of a boat.



Although this part of the study shows less of how the model can be used in the classroom, its impact to the student teacher was great. It supported the student teacher to experiment and to deal with uncertainty. Identical to Capobianco’s (2011) study, the collaboration allowed critical discussions, encouragement and meaning making of what the students were learning for both the teacher and the author. The role of the author was to ask questions, provide additional information and support. With all this, the student teacher created a successful lesson, improved her skills, and gained more experience and most of all, confidence.

6.6.2. Testing the model with the experienced teacher

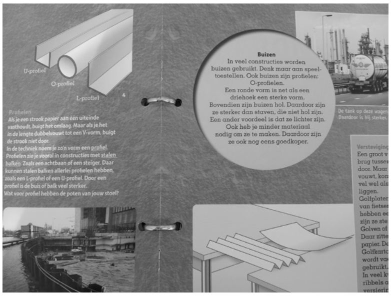
The second teacher worked in a public elementary school in the Netherlands. The teacher was the same one with whom the author conducted the study about systems in Chapter 4. This time she had 24 pupils in her class, age between eight and ten years. The class was a combination of children from two grade levels. Thus, half of the class was familiar to the author as well; the teacher was their teacher the year before. Detailed description of her teaching style and classroom can be found in section 4.5.

The topic of the lesson was constructions (Picture 8) and the lesson lasted 90 minutes. The main concept of the lesson was stability and it was approach through following questions:

- What is construction?
- How do you make a steady construction? and
- What is the role of the supporting parts in it?

Furthermore, the lesson was divided into three parts: an introduction, core of the lesson and an evaluation.

The introductory part of the lesson is presented in Table 10. This part was 20 minutes long and included movements between all the domains of the model, social context (S), concrete object (C) and abstract knowledge (A). First column of the table shows the duration of each task. In the second column the addressed domain is presented. The last column shows what the teacher had planned to do or teach



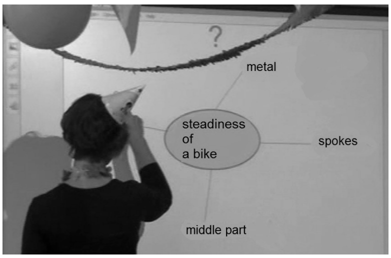
Picture 8. Text book for the theory part of the lesson.

at each point.

After the discussion (First cell in Table 10.), the teacher collected on the SMART Board the terms used to describe the steadiness of a bike (Picture 9). One of the pupils wanted to continue the discussion about the middle part (extract below).

> Pupil (P1): "*If that breaks* (points at the middle part of the bike) *then it doesn't stay* (in one piece)."
>
> Teacher (T): "*So, this* (touches the middle part) shouldn't be broken"?
>
> P1: "*No, it shouldn't.*"
>
> T: "*And how is that? How come the middle part makes it so steady?*
>
> *That is a very important part of a bike.*"
>
> P2: "*Because the triangle is the steadiest of the forms. "*
>
> T: "*Because the triangle is the steadiest of the forms. "*

This part of the extract shows the discussions in boxes 4 to 6 in Figure 13. The pupil thought out loud about what he considered as the most important part of the bike. At this point the discussion was concerned about the concrete objects that the pupil could see in the classroom. His idea was still a bit too immature, thus, he could not explain fully the reasons behind steady constructions. However, the teacher was able to use this opportunity and instead of answering the question by herself, she received the answer from



Picture 9. Teacher finishing the mind map of ideas.

Table 10. Teacher's plan for the introduction.

Part of the lesson	Domain	
Introduction: 20 min	S/C/A	Bike from one of the pupils. What makes bike steady? (Mind map).
	A	Demonstrate steadiness by using a triangle and a square made from bamboo.
	C	Discussion about constructions. Where in the class room do you see them (first within own group all constructions that you can see, then one answer per group to whole class)?
	C	One short movie about bridges.
		Distribution of the exercise books (one per two pupils).
5 min	C/A	Look at the pages 56-57 in the exercise book, read the questions and answer.
		- Talk about terms (construction, triangle, profile, metal bars).

one of the older pupils. From that point on, both the teacher and the other pupil moved on to the domain of abstract knowledge for the explanation. Below the extract continues.

> The teacher demonstrates the steadiness with a triangle and a square, both shapes made from bamboo sticks. The triangle does not alter its shape when the teacher plays with it, unlike the square.

> T: (Holding the square in her hands) “*Indeed, the triangle form is a very steady form.*”
>
> P3:”*If you place here* (draws a line diagonal through the square) *another bamboo stick, and then this also stays* (in form).”
>
> T: “*Aaah, smart. What P3 said is that if you place* (does the same hand movement as the pupil) *here another stick then…*”
>
> P4: “*But then there comes a triangle in.”*
>
> T: “*Then there is indeed a triangle…”*
>
> P5: “*Two triangles.”*
>
> T: “*Yes, then there are two triangles in*”.
>
> …
>
> T: “*This is a way to make a square form steadier.*”

This latter part of the extract shows in more detail what happened in boxes 7 and 8 (Figure 13). After finding the answer to the question, presented in the previous extract, the teacher moved from the abstract knowledge domain back to the concrete object domain. Here the pupils used the learned concept of ‘triangles being the steadiest forms’ and used this knowledge to improve a square construction. This can be seen as a movement from the concrete object domain (demonstrations with the bamboo forms) to the abstract knowledge domain. The pupils applied the abstract knowledge they acquired by observing the structures of the bike to the bamboo structures. The extract presents pupils using the concept in another case without teacher’s initiative.

Picture 10. Pupils testing the strength of different profiles.

The lesson continued with a recap of what constructions the pupils saw in the classroom. The answers of every group can be seen in Figure 13, box 10. The answer of the last group was the 'team box' (see Picture 10, a green box) that every group has on their desk. The following extract shows a pupil questioning the other team's answer. He believed that the answer did not fulfil the criteria of steadiness based on what he had learned.

> T: "*The team box is from a specific material, in a specific form and the parts are made so that as they are put together they form a box.*"
>
> Pupil (P6): "*But this is not steady*"*?!?!*
>
> T: "*But the material is different. Hey, but this is a good one. Pupil 6 says that this is not steady at all but the material is strong, steady plastic. … You do not choose steel bolts and such. If you make this from steel it is indeed steady, but then again it becomes heavy. Therefore, you have to think what it is made for.* "

For the mind map the pupils listed important factors that make a bike steady. One of them was the metal that is used in the bike. Here, the pupil (P6) was confused about what makes something steady. Until this point, the steadiness was approached through the bike and heavy metal constructions such as bridges and buildings. In the case of the 'team box', this line of reasoning did not apply anymore and the pupil questioned it. This type of reaction can be seen as the pupil reflecting the learned concept to what he is experiencing.

The following figure (Figure 13) presents how the movements between the domains actually happened during the introduction part. Yet again, these domains are knowledge domains and therefore, describe the knowledge of social context, the knowledge of concrete objects and the knowledge of theory-related concepts (abstract knowledge).The influence of the model is presented with the actual connections and reactions. The lesson plan itself does not ensure what happens during the lesson and the use of the model could have stayed on the planning level alone.

Overall, the teacher connected the concrete objects well with the abstract knowledge that she wanted to teach to the pupils. However, the connection to the social context happened only once in the beginning of the lesson. This is because riding a bike and a bike were not the actual social context and the concrete object of the lesson. The bike only inspired the pupils to discuss about steady constructions but the actual context of the lesson was building bridges and towers, not riding a bike. The model suggests that the other two domains, concrete object and abstract knowledge, take place within the social context set for the assignment. In this case the bike was a good example and the pupils related to it strongly but as a concrete object it was needed only for a short part of the lesson.

It appears that this approach made the pupils aware of the different concepts affecting a construction and the different methods to build. They seemed to think critically about the criteria for steady constructions. Furthermore, it is possible that without the teacher being aware of the domain shifts, she might have missed the confusion presented in one of the extracts (steadiness of the 'team box'). The teacher replied to these thoughts by linking the pupils' experience with an object to the abstract knowledge that was needed to understand the issue. She was able to give the pupils another perspective that deepened their ideas.

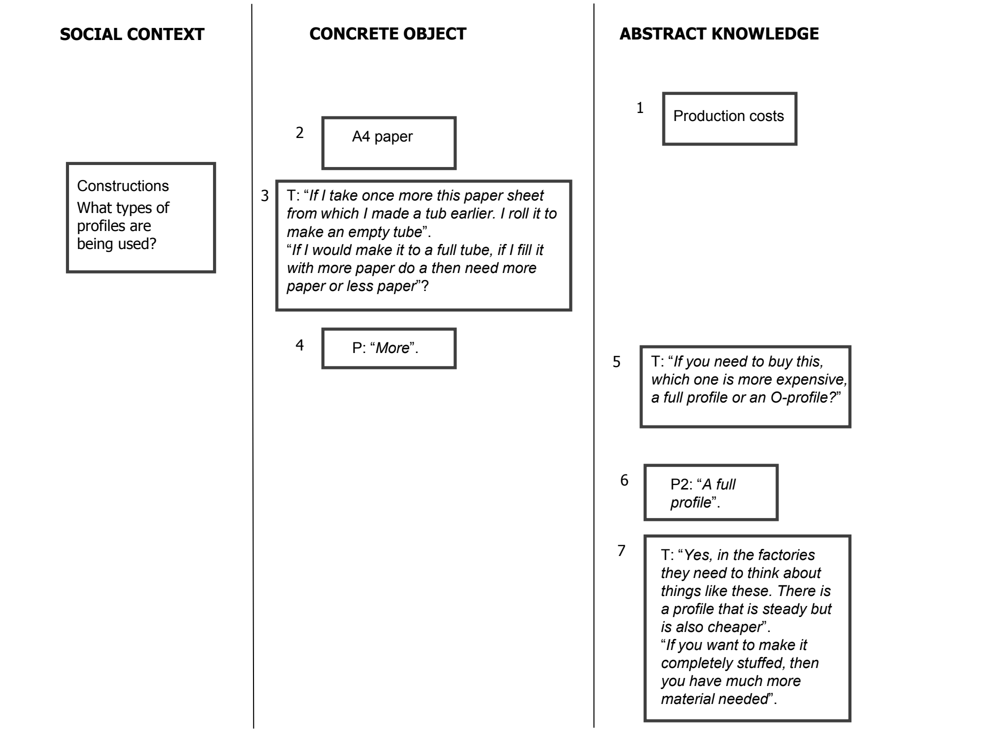
In the core part of the lesson (Table 11), the pupils experimented with different types of profiles (Picture 10). Materials were plain A4s, a string to hold the weight and scissors as a weight to test the strength of the paper. These experiments originated from the study material that the teacher used in the lesson.

When the teacher explained different profiles and the benefits of using them in constructions, she felt that additional knowledge of the benefits of using an O-profile is needed. In Figure 14 the teacher's approach is shown.

The extract below is an example of the explanations the teacher gave throughout the lesson. She did not plan this example beforehand but she was able to give an answer. She used the approach of the model to answer to the questions from the pupils. She kept in mind how to connect abstract knowledge with a concrete object.

The biggest part of the lesson was dedicated to build towers from ready-cut pieces of paper (Picture 11). The groups that the pupils worked in were the same ones they sit in the classroom. The goal of the assignment was to build a tower as high as possible that would still be steady. The pupils chose their approach by themselves.

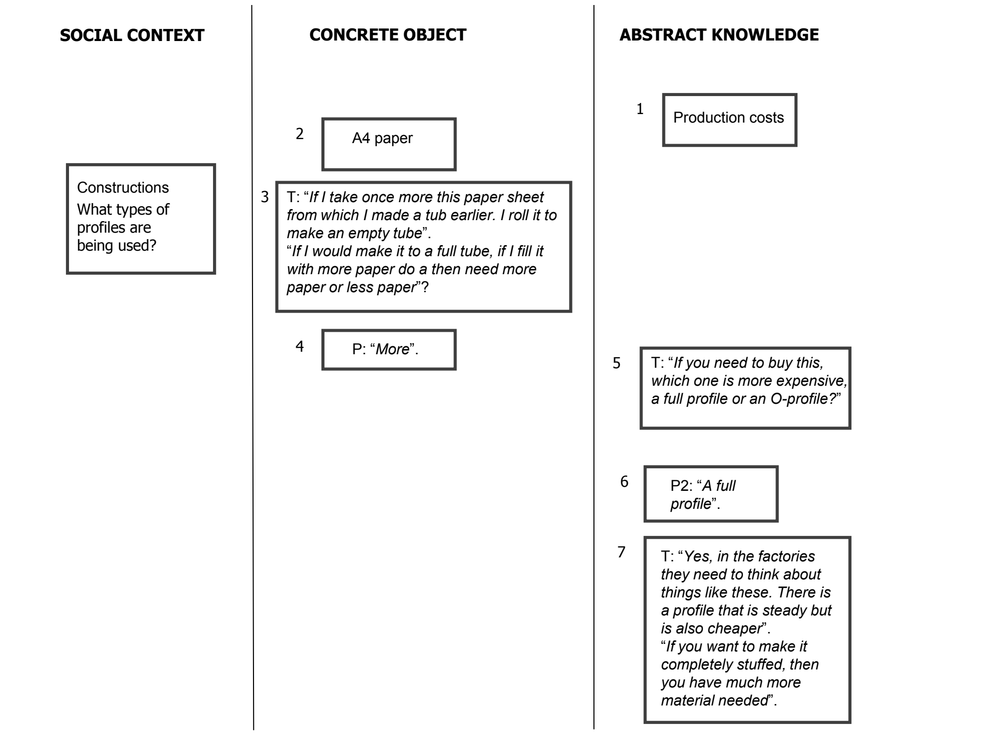
Figure 13. Movements between the domains.



Also a feedback part was included, during which each team gave feedback to two other groups (see Table 11, Team on Tour). This seemed to be the hardest assignment of the lesson. In their feedback each group had to give one positive feature about the tower of the other group as well as an improvement point.

Figure 14. Teacher used the model to reply to the pupils question about production costs.

Table 11. Second part of the lessons.



Core: 10 min	S/A	1) Read and look at the illustrations on pages 58-59. - Three short movies about steady buildings. - Demonstrations: O- profile (rolled paper) and L-profile (folded paper).
5 min	A	2) Four questions about topics learned (game played together).
10 min	C	3) Experiments with the paper -> make profiles in pairs and test. Afterwards discussion in the class.
35 min	C	4) Make towers from paper in groups of four. In the end measure the height of each tower.
	A	In between: Team on Tour. Group 1 writes tip and top for groups 2 and 3, Group 2 for groups 3 and 4 etc.

However, “*really nice*” or “*good*” were offered as something positive about the project and suggestions such as “*less glue*” were given as ‘tips’. The pupils reflected on their building process in order to develop an understanding of their design process (Zubrowski, 2002). The feedback did not only allow the pupils to compare their own design to the others but each group defended their design choices against the feedback received. They seemed to improve their own design process not according to the feedback but by discussing what can they apply from the work they had seen in other groups.

The table above (Table 12) presents the plan for the evaluation part of the lesson. The pupils had to evaluate how their project went and give justification to the decisions they had made. They discussed whether the tallest tower is really the steadiest, and what compromises needed to be made to build the highest tower or the steadiest one. The reasons given by the pupils are described below.

The highest one (triangle form applied on two sides, see Picture 11, middle part): The choice of making only two triangles instead of four was because of the time. They wanted to be as quick as possible. This group was the only same gender group; namely girls. The girls functioned in an effective way in which the goal was clear to all the members of the group. Colfer (2011) reports that in same gender groups, “girls use stereotypical affiliative language”. They also repeat each other’s words and ideas to gain understanding. However, creativity and critical thinking are not evident in these groups (Colfer, 2011). It appears that also in this group the girls agreed on one’s suggestion and the talks were cumulative.

2nd highest (no triangle form used): They wanted to build as fast as possible and thought of adding the triangle form later. However, in the end there was no time.

3rd highest (triangle form used partially): Later on in

Picture 11. Pupils building the towers.

Table 12. Final part of the lesson, where results are discussed.

End: 5 min	C/A	Discussion over the towers. Which one is the tallest? Which one is the steadiest? How can you control it? Why is this tower steadier than the other towers?

the project they started to add triangles (on two side of the cube), when they noticed an example in the work books.

4th highest (triangle form applied on all four sides): After 10 min they saw other groups making triangles, so they decided to do that as well.

5th highest (triangle form applied on all four sides): No evaluation (students were needed somewhere else).

6th the lowest (triangle form applied on all four sides): All four sides were supported by the triangle construction. They learned during the lesson that triangles were needed to obtain a firm object.

Unlike the students in Zubrowski (2002) the pupils here were able to verbally explain and defend their choices of action. The pupils made decisions based on what they observed from the other pupils or from the learning material. Some of these were successful and others not, but behind an action there was a decision and the pupils could articulate their reasoning. The teacher's explanations and the feedback session (Team on Tour) in the middle of the building phase made pupils observe and helped them to evaluate their process. There was enough support and time given to the learning.

As homework, the pupils were told to investigate where they could see constructions with triangle forms. Few days later the teacher reported back that this was a success among the pupils. The next morning (after the lesson) the pupils had enthusiastically explained where they had spotted firm constructions. Svensson and Ingerman (2010) and Zubrowski (2002) have addressed the importance of making technological artefacts noticeable to pupils in 'technological' situations inside and outside the school. Based on the feedback received by the teacher the idea of linking technology to the environment of the pupils resulted to an overall experience of technology. This enabled making the links between technological objects, human intentions, the function of technologies, social context and human acts clearer to the pupils (Svensson & Ingerman, 2010).

6.6.3. Teacher's evaluation of the use of the model

The teacher explained that she often uses real-life situations, even during mathematics lessons. She does this not only to show to the pupils why something is important to learn but to wake the curiosity in them as well.

The teacher mentioned that she was already familiar with using all the domains presented in the model; as separate things, however.

> *"I was already familiar with the three domains used in the model. However, the need to move between these three domains during a lesson was new to me."*

She realized that she needed to incorporate the domains into her teaching, not only work with them in pipeline.

> *"Now (after using the model) I see the need of incorporating the domains, not in*

> *a pipeline. But moving from one to another, just to make sure pupils will*
>
> *understand the connection. It made me aware of the seeral steps I had to take during the lesson, which was helpful. "*

She stressed that by linking the domains and moving between them helped the pupils to understand the connections between concrete examples and abstract explanations.

She started the planning of the lesson by analyzing the three domains related to the lesson content, as well as the possible movement between the domains.

> *"I used a pupil's bicycle to create a surprising introduction related to their daily lives. Thus, they were able to examine a concrete object, which helped then in thinking about our starting question (namely: what gives this bike its steadiness). I incorporated several movements of collective reflection between the domains between these domains."*

And then the teachers gives a small list of examples such as, social and concrete domains were connected when the pupils were looking for constructions in the classroom. Another example of movements from abstract knowledge to concrete object was when the pupils observed paper towers made by the others to see what profiles and constructions were used. She stated that the pupils responded to this new method as she expected.

The school where the teacher works practices a method called co-operative learning. Besides this, the teacher wanted to introduce some structure to the lesson and found that the model provides this to her. She said that including both of these into a lesson required more work than merely following the study material designed for the lesson. To a question did the use of the model provide her more confidence to give the lesson or did she feel more prepared, the teacher answered:

> "*I did not exactly feel more prepared than I would feel with my usual lesson plan. The model made me aware of the need of several movements between the domains in order to gain a better connection between the theory and practice. Especially during the lesson this was helpful for me. When I thought a connection was needed (again) I tried to obtain this using a proper question. "*

Because she was aware of the connections she added an extra explanation when needed. To make the benefits of using an O-profile clearer, she added an explanation of how by using less material cheaper productions costs accomplished. In overall, the model helped her analyse and improve the lesson.

6.7. Discussion

The literature study demonstrated reasons to why the three-domain model is a useful aid for teachers and how they can benefit from it in a sense of professional development as well. In the study presented in Chapter 2, the trainer of one of the professional training sessions encouraged in-service teachers by saying "*What we do in here is as much as science as anything.*" The model wants to help teachers to achieve this type of approach to science and technology education. From planning the lesson to teaching it, the model will help teachers to bring together information from different domains. When concepts are approached as such, the knowledge of them is built gradually and in a more investigative manner. The technique of the model applies two principles to teaching. One of them is the three domain-approach, where social context, concrete object and abstract knowledge are used together to teach science and technology concepts. The other one, as important as the first one, is the constant movement between these domains.

The two studies shown in this chapter demonstrated that the model is relatively simple and straightforward to apply in to a classroom environment. It is not too abstract to implement in practice either (Boulton-Lewis, 1994). The model is easy to understand and this can be accomplished with one practical example of how to use and design a lesson that uses all three domains. Only requirements are that teachers understand the meaning of the domains and the movements between them. The experienced teacher participated in a workshop where the model was presented. After this, she was able to plan and teach a lesson of her own. The student teacher studied the model by herself and decided that the model provides the type of approach that she prefers to technology lessons. With her the involvement of the author was bigger. This, however, was merely to discuss teaching and explore different possibilities within the approach of the model. Naturally these conversations had an influence in her teaching but she also said that because of the model she was more confident to give the lesson.

Gomez-Zwiep (2008) reports teachers' tendency to see knowledge construction as a linear process. Daugherty and Custer (2012) as well as Gerard et al. (2011) emphasize the importance of reflection ideas. The student teacher said in her evaluation that she would have stopped adding knowledge to the phases of the design project if she had not planned the lesson based on the model. She explained that she was looking for appropriate moments to bring more insight to the pupils and she would have missed those moments without thinking in terms of the model. The more experienced teacher also realized that it was essential to incorporate the domains into her teaching, not only work with them in a form of a pipeline. She did not only add new knowledge like the student teacher did, but also integrated the new knowledge, like Gerard et al. (2011) recommend. In both of the cases the teachers realized their standard approach to teaching, in which they both would have worked in a linear way. Because they used the model to plan their lessons, they confirmed frequently where the pupils were in their learning process. They built the knowledge with the children. Both of the teachers were able to implement this idea in practice as well.

The experienced teacher was familiar with the domains of the model. She, however, was not familiar with the movements between the domains. She describes in her evaluation that the model made her more aware of the necessity of several movements between the domains to gain better connection between theory and practice. In Chapters 2 and 3 it is described that one of the issues in concept learning in science is lack of connections between theory and practice. The experienced teacher became aware of while working with the model. She was able to link the questions to a concrete object or abstract knowledge, depending on the case. Based on this it is possible to move away from the approach where a teacher starts with the knowledge that pupils have and thinks that after instruction additional knowledge is built on it (Gomez-Zwiep, 2008). She knew what the learning goals of the lesson were but she was also aware of the fact that one explanation may not be enough.

The student teacher worked with the model throughout the series of lessons. She evaluated the situation with the help of the model before each lesson and used the model to choose an approach that was the most useful at the moment. In this manner she presented the appropriate information when the ongoing situation of comprehension was at hand (Branford & Johnson, 1972). She also avoided moving ahead in her instruction without reflecting her next move to her students' knowledge (Gomez-Zwiep, 2008).

Both of the teachers offered several opportunities to the students to communicate their understanding and there was room in the lesson plans for the students to express their ideas (Spektor-Levy et al., 2009). The experienced teacher had space in her plan for communication and ideas. She created a learning experience from the pupil's question. Without allowing the pupils to think out loud, the other aspects of the concept at hand might have not been explored. The student teacher got feedback from her students about the current knowledge level by including presentations to the design project. In these presentations the students expressed what they thought are the most important requirements for their design. Later on the teacher continued from these requirements and they were developed and specified further.

The next day, when the pupils of the experienced teacher came back to school they were enthusiastic to tell what types of constructions they saw on their way home. This is just one example but in this case the education succeeded in becoming part of the pupils' everyday life experience. Furthermore, the model seems to help pupils to learn concepts as well. In Figure 13, box 8 and especially box 11 show pupils using and discussing the concepts taught to them. The model did not only show a perspective to the teachers to explore the concepts but it also helped teachers to recognize student output and students to explore the concepts. In the end every teaching aid aims to help student learning one way or another. Such a feedback is a promising start for future research of the model.

6.8. Conclusion

The model introduces a method for teachers that helps planning lessons and provides an aid during these lessons. The model offers a tool that is not too abstract to be applied to the classroom. Nor is it too shallow that it only offers short-term fixes. Furthermore, its development is based on theory and it has a clear aim at what it wants to accomplish.

In this paper two successful examples of the model at work have been shown. Both teachers reported that they benefited one way or another from using the model in their preparation of the lesson as well as during the lesson. The teachers realized the benefits of non-linear teaching method as well as the profit of collecting information together and combining knowledge. During the lesson(s) the student progress and knowledge was recognized by the teachers and they responded to it accordingly. And the concrete objects were indeed connected with the relevant theories.

As far as the experienced teacher was concerned, only a short presentation of the model was needed for her to be able to execute the lesson. In her lesson the movements between the domains are clearly visible, both in her teaching and in the responses that she gave to her pupils. Even though she was an experienced teacher and comfortable with her teaching style, she learned something new that improved her teaching.

The student teacher on the other hand needed more help with preparation but in the end, she also planned and taught a lesson that satisfied her expectations. In her lessons the model was used for planning and to give her confidence to carry out the lesson. The results are not self-explanatory but became evident during post-lesson discussions.

To plan a successful lesson using the model, certain conditions need to be met. In both the cases mentioned here, it was established that that teachers understood how to use the model and what its limitations were. Furthermore, both teachers had a clear idea of what they wanted to teach. The experienced teacher had chosen constructions and triangle shape. The student teacher chose to teach her students a design cycle. The topic in both cases was well planned, narrow as well as complex enough with respect to the age of the students. On a larger scale, it is necessary to meet these conditions in order to prove that the model can be used as a teaching and learning aid.

Up to now we have discussed issues in science and technology concept learning. The three first chapters demonstrated issues that acquire attention in teaching and learning science and technology concepts. The two last chapters have offered a possible solution to these presented issues. In the next chapter this research will be concluded and connected to other views on teachers' professional development.

Chapter seven

7. Conclusion

Sci·ence teacher's required skills and competencies are well presented in official documents, frameworks and standards. The proposed framework for K-12 (includes both primary and secondary education) science education in the USA by National Research Council [NRC] (2012) requires teachers to have a strong understanding of scientific and engineering practices, cross-cutting concepts, and disciplinary core ideas. Teachers should also be able to recognize common pre-scientific notions that students have and reflect them in their own questions (NRC, 2012). In order to do this, teacher preparation and professional development programs will need to offer learning opportunities for teachers to deepen their conceptual understanding, engage them with scientific and engineering practices, and develop an appreciation of science (NRC, 2012).

Another document from USA "Standards for Technological Literacy" (International Technology Education Association [ITEA], 2007) briefly discusses the importance of providing teaching staff with professional development activities and in-service programs to facilitate the application of the standards into practice. The document continues to encourage everyone who is interested in technological literacy to understand the importance of technology and support it as a basic field of study in schools by developing policies and providing funding that allows teaching implementation of technology from kindergarten to twelfth grade (ITEA, 2007).

In order to prepare future teachers to teach science, an elementary science education course should provide time to consider an idea, and give student teachers personal experiences of its potential to explain and solve practical problems (Gustafson & Rowell, 1995). In-service teachers need to be knowledgeable about the content they are teaching as well as familiar with constructing and testing everything their students will construct (Kolodner, 2002). Most importantly, teachers need to experience iterative cycles of designing, doing and reflecting, and put their skills into practice with children (Kolodner, 2002).

In light of what science and technology education needs to be and what teachers can do, this chapter connects the findings of this dissertation to broader issues. Firstly, a summary of earlier chapters is provided in section 7.1. Section 7.2 provides a short introduction to other (professional) learning models for teachers. Since the testing phase of the model is in its preliminary state, the potential of the model, and on the other hand its limitations are discussed through literature. Section 7.3 discusses how development and testing of such models should go and where to pay attention. Similar successful small scale studies of teacher's professional development are presented in section 7.4. This section is included to validate the results of this dissertation and that the application of model in to practice is repeatable. After the successful teachers' professional development ideas, section 7.5 discusses, with the help of two other studies, the problematic nature of improving classroom activities and including teacher's professional development into daily classroom practice. And last, section 7.6 concludes this dissertation with recommendations.

7.1. Summary of the findings

Learning science and technology concepts and exploring the practical approaches to do that were the two ideas behind this dissertation. This research has provided new insights into the knowledge level of teachers and pupils in science and technology, and it has offered a method to help teaching and learning of science and technology. The list below shows roughly the steps taken during the course of the research.

1) Identification of the problem: lack of proper science and technology concept knowledge,

2) Suggestion for solution: the three-domain model, and

3) Preliminary tests of the solution.

Thus, the research began by indentifying the problem. The study presented in Chapter 2 investigated primary teachers' knowledge of science concepts related to air and water. The data was collected mostly by means of pre-lesson assignments. The analysis was generally based on the written answers but observations made during the training were taken into account as well.

The analysis revealed that one of the shortcomings in the observed in-service teacher training activity was that the method used does not provide enough support for teachers to connect a concept to its practical application. As the trainers did not assess teachers on the learned concepts, there is no guarantee that the concepts were actually learned. In fact, post-training assignments showed that the teachers had not comprehended what they learned; it is therefore, unlikely that these concepts will be used in practice. Therefore, extra attention needs to be given on describing the concepts in a way that an understanding can emerge within the teachers.

Chapter 2 argues that the teachers have various pre-concepts that do not match with the ones used and taught in science (and technology). These pre-concepts exist for a reason and they help teachers to deal with the practical situations in a relatively successful way. These concepts are based on teachers' experience on what works in certain situations but these 'facts' remain limited to that particular situation. In order to learn concepts that can be applied universally, learning the 'proper' concepts, that is, the way they are used and taught in 'real' science and technology does have a value. These pre-concepts set a starting point for learning. The trainers involved in teacher's professional training need to be aware of them and they need to be guided to reach that awareness.

Teachers' professional development activities have potential to improve teaching practices if more attention is paid to how theory is connected to practice. At the moment this connection is missing or not emphasized enough. The difficult, science concepts need a connection to a practical, tangible product in which the teachers can see the concept being used. Without connecting the concept to its application, the teachers cannot use the knowledge and they miss the possibility to fully explore science and technology in practice.

The issues, to which a relatively short professional training cannot offer a solution, suggest that maybe in-service teachers' views on teaching and learning science and technology are a result of their pre-service education. Therefore, Chapter 3 continued to examine science and technology concepts of students studying to become teachers. The same questions, designed for the study in Chapter 2, were used in here. Only slight moderations to the questions were made on request of the teacher trainers.

The study revealed that the student teachers had a tendency to link the concepts at hand to tangible properties, in a similar manner as the in-service teachers in the previous chapter. The analysis showed that they were able to provide an answer to the post-lesson questions if the trainer had given a matching example of the concept during the lesson. When a question was approached from an angle different to the trainer's example, the answers showed insecurity. Without a concrete example of the concept, a relatively small change between pre- and post-lesson results was seen.

To broaden the view of how science and technology is taught in schools and how concepts in these two fields are approached, Chapter 4 examined teaching of a concept to young pupils; namely systems thinking. The method included structure interview with the teacher to see what her level of systems thinking was, intervention where the 'answers' to this interview were given and explained to the teacher, a pre-lesson interview to the pupils, lesson planning together with the teacher, systems thinking lesson and observations, and a post-lesson assignment to the pupils.

The exploratory study showed that pupils did not consider the existence of feedback in a system and the emphasis was on the experience gained by using such a system. Pre-lesson interviews showed that the concept of input was more obvious to the pupils than the concept of output. However, post-lesson results showed that the most noticeable change had happened with respect to outputs as the latter were more present in pupils' answers. Furthermore, the systems used in the interview as well as in the post-lesson assignments were described in terms of what a user can do and experience while using such a machine. In these cases, what a user and what a machine does overlapped and this made setting the system boundaries more demanding.

The results of the study on young pupils' systems thinking are promising. However, choosing the right approach asks more planning from the teacher than might appear at first. The idea of what inputs and outputs of a system are, needs to be clear to the teacher first and then introduced gradually to pupils. As recommended in Chapter 4, the learning of systems thinking should start by using systems that are already familiar to pupils. Thus, setting the boundaries to a system and consequently to the investigation is this way easier. This can also help in distinguishing the difference between a process and a system.

The two first studies gave an impression that teachers require help forming an explanation and thinking in terms of cause and effect. Additionally, pupils' user-driven approach to systems hid underlying concepts and the focus was only on what could be seen and experienced by using technology. Since both the in-service training as well as the future teachers' education has limited amount of time to teach science and technology concepts, an aid that helps teachers towards cause-effect reasoning and coherent argumentation is needed. This aid for teachers could help them teach their students away from one-way thinking as well.

The model presented in Chapter 5 provides an aid for teachers to plan and teach science and technology lessons. The model approaches the lesson and its planning in an investigative manner. It combines and connects practical and abstract knowledge throughout the learning process. This model distinguishes three domains: the social context, the concrete product and the concepts. Through these domains it addresses the learner's preference for tangible properties of concepts by including the concrete object domain in the middle of the model. It connects theory and practice with a social context that makes sense in that learning moment. The model provides boundaries to the lesson but it is also flexible in order to give room to creativity. It helps both students and teachers explore cause and effect thinking. Furthermore, it provides perspective to the lesson by presenting information at the appropriate learning moment.

In Chapter 6 the results of preliminary tests of the model are presented. Two teachers used the model to plan a whole lesson. During the planning they used the model to collect the required information. Teachers could accumulate this knowledge based on what they already knew about the topic and build on top of it. This also prepared them to answer to the questions their students had during the learning process. When faced with the problem of how to explain, movements between the domains helped in choosing an approach and made the situation clear to both the teacher and the students. Thus, elements of cause-effect reasoning came naturally into play.

This section has given a short summary of what was found in the three studies and how the model was developed based on the work and findings of those studies. Also preliminary test results are shown and discussed. In the following section other models for teacher learning are presented. Because this dissertation aims at providing an aid for teachers to teach science and technology, it is worthwhile to see how others have approach similar issues. Although in the following more general models and ideas are presented, the reason why teachers' professional development offers an interesting field to explore becomes evident. This reflection also provides a framework to the future development of the model.

7.2. Models for teacher learning

The main purpose of a school is to make children learn, the same school should be seen as a main place for the teacher's professional development. Unfortunately, for a long time teachers have been seen as passive towards their own professional development. Probably for this reason many of the early models concerned with teacher learning are linear.

Coenders (2010) and Marcelo (2009) present several models for teacher learning. They both start by introducing Lewin's linear model where a teacher's in-service training will naturally be followed by changes in teacher's knowledge and beliefs which in turn will lead to changes in classroom conduct and result to positive changes in student learning. Further studies have led to alterations of the model. Guskey disagreed with Lewin and argued that based on professional development activities, a teacher changes his/her classroom practice which leads to change in student learning results and this leads to change in the teacher's attitudes and beliefs (Coenders, 2010; Marcelo, 2009). The linearity of both of these models has been questioned and therefore, cyclic models have been implemented.

Coenders (2010) continues by introducing the Concerns Based Adoption Model by Hall and Loucks, where teachers go through a change when they need to prepare for a curricular reform. This change means that they have to unlearn or change some of their teaching skills in order to adapt new ones (Coenders, 2010). According to Marcelo (2009) Clarke and Hollinsworth have criticised earlier models for not presenting the complexity of the teacher learning process by being linear and not interrelated. Therefore, they created a model describing the growth of professional skills and knowledge (Coenders, 2010; Marcelo, 2009). In the model, change happens through the mediation of application and reflection on four different levels; namely the personal domain, the field of teaching practices, the consequences in student leaning and the external domain (Coenders, 2010; Marcelo, 2009).

The last model that Coenders (2010) introduces in his dissertation is the one by Joyce and Showers. The inventors had a vision for teacher's professional development where new knowledge is added to teacher's already existing professional repertoire. According to Joyce and Showers, a professional development program will be successful if it includes a) theory that explains the thinking behind the invention, b) demonstration of the innovation, c) practice under supervision, d) non-evaluative feedback as soon as possible after the practice, and e) coaching after the training at the workplace (Coenders, 2010).

For a researcher, these models offer a good starting point and a reflection tool. The vision of Joyce and Showers (2002) addresses the bond between student achievement and staff development. In their book, from the first pages on they focus on the following: if teachers spend a dozen days in a school year to study their field or a teaching strategy as well as regularly reflect on the implementation and student learning, the student achievement will rise (Joyce & Showers, 2002). This idea offers a base for reflection and overall view of where to aim with the development of the model presented here.

However, teachers most likely need outside help to benefit from these learning models and to be able reflect them on their professional development. This was one of the thoughts when the designing of the model started. These models help on a 'meta-level' and offer a reflection tool to professional learning. Yet, someone needs to translate the ideas and concepts presented to teachers. Hence, the model discussed in this dissertation offers an approach that can be adapted with a little effort and within a school environment.

7.3. Potential and limitations of the model

Since the above presented teacher's professional development models are rather abstract, in the following, similar experiments than the preliminary tests of the model are reflected and compared to the model research here. It is useful to see how others have succeeded in similar efforts. The point of this comparison is to see whether similar results could be obtained with other teachers and what could be the common factors influencing success. The work of Borko (2004) is used as a validation tool. This reflection gives an overview of how development and testing of such models should go and where to pay attention.

Borko (2004) has divided types of research in teachers' professional development into three phases. Each of them builds on the previous one. In the first phase, research activities focus on an individual professional development program at a single place of activity. At this phase the study focuses on the professional development program, teachers as learners, and the relationship between these two elements. The trainer and the context however, remain unstudied. In the second phase, the research builds on and explores a single professional development program executed by more trainers at more than one place of activity. This time around relationships among trainers, the professional development program, and teachers as learners are at the centre of the study. The last phase broadens the research scope and compares multiple professional development programs, each held at multiple sites. At this phase, four elements of professional development are studied: the trainer, the program itself, teachers as learners, and the context. According to Borko (2004), by following these phases any research can ensure a way to provide high-quality professional development for all teachers.

The development of the model presented in this dissertation uses data from one professional development program (VTB-Pro) executed by more trainers, at several place of activity. It was tested, however, only with two teachers at two schools. The model has proven its power in these two studies but in order to be reliable on a larger scale, a larger sample of teachers and students as well as schools need to be investigated. However, because this dissertation is a result of a PhD research, the larger scale study is a task outside of this work. The time given for this research was limited to four years and what was possible to do within this time frame is presented here. This dissertation focuses on offering a theoretical framework of the model and preliminary test results as a basis for future research. This study can be seen as a phase one research of professional development activity.

Borko (2004) describes the purpose of phase one activities as follows: "*to provide evidence that a professional development can have a positive impact on teachers' learning*". Likewise, this qualitative dissertation aims at showing an existence of a phenomenon. This is a proof that something exists but naturally, it does not prove everything. In her article Borko (2004) lists many aspects in teachers' professional development that have been improved. Borko (2004) bases her argumentation on studies and examples of effective development programs and their effect on teacher learning. In the following, those aspects that apply to the results of this dissertation are reflected to the findings.

In order to reveal how professional development changes individual teachers, Borko (2004) focuses on three characteristics; subject matter knowledge (SMK) for teaching, understanding student thinking, and instructional practices. To support the students' conceptual understanding, teachers have to have rich and flexible knowledge of the subjects they teach (Borko, 2004). At first, this sounds rather ambiguous and maybe even too optimistic. It may be even hard to reach since, as discussed in the previous chapters, teachers have a tendency of not using their science and technology knowledge in an optimal way. Instead of trying to learn everything about certain topic before entering the classroom, a teacher can approach it like the model suggests. Naturally, a teacher needs to know more than the students, but the richness and the flexibility come from the way the knowledge is used, not from the amount. The model helps to gain a sufficient knowledge base by offering an aid to collect and combine information together. Teacher can collect central facts and explore the possibilities of the topic in a way similar to what the students will do. Adding new knowledge and determining important facts and claims as the learning progresses belong to the process as well.

To guide the students' thinking, teachers need to understand how children's ideas about a subject develop and how to connect student ideas with the important ideas of the discipline (Borko, 2004). The model invited the teachers to look for an input from the students and their thinking. During the lesson planning it was assumed that the questions will arise; as a result, the two teachers were reportedly more prepared to answer to students' questions and used the student input to direct the lesson.

In a report by National Science Foundation (NSF), Lieberman (1995) expresses similar interest in students' ideas and thoughts. Lieberman (1995) gives an example of how to learn by observing students. She uses a guide for collecting evidence in order to understand how students become literate at the primary grades. The Primary Language Record (PLR) encourages teachers to observe the habits of students and the choices they make when they are learning (Lieberman, 1995). This guide helps teachers see that students learn and think differently and that they engage with fellow students in many different ways. Most significantly, the guide does not tell teachers what to do. It expands on teachers' understanding of what is possible and how to use their own professional judgement better (Lieberman, 1995).

7.4. Success stories

The suggested model focuses on the planning of a lesson and on using it during the lesson. For future research, it is worthwhile to investigate whether other teachers could succeed in similar attempts. In this section, comparable studies and teacher development projects are discussed.

Focus points in attending physicians' work during clinical rotations have been highlighted in a study by Irby (1994). He lists three aspects on what clinical teachers in medicine need to know in order to facilitate learning. First, the teacher needs to assess the learners' knowledge by asking questions. Irby (1994) emphasizes that this is not only done to find 'misconceptions' and gaps in knowledge but it also activates the learners' prior knowledge. By doing this, the teacher receives feedback as well. By asking questions from the learner, the teacher does not move ahead without reflecting the next move on the students' knowledge (Gomez-Zwiep, 2008). Irby (1994) emphasises that during this inquiry process it is important that the teachers have a flexible knowledge base, since there is no standard way according to which learners structure their learning.

Borko (2004) also describes results from a Cognitively Guided Instruction (CGI) project, where teachers reported an increased awareness of the role that children's thinking plays in learning as well as the importance of listening carefully to students in order to build on their understanding and 'misconceptions'. To investigate the instructional practices of teachers, CGI teachers were compared to a control group. The results showed that CGI teachers taught problem solving more often than the non-CGI teachers (Borko, 2004). The teachers also attempted to support their students with discussions on problem-solving strategies, listen to them to talk about their thinking, and use students' responses to assess their understanding and match follow-up strategies to their abilities (Borko, 2004).

When working with the model presented in this dissertation, the two teachers showed similar attempts. The teachers listened to and used the student feedback to proceed with the project and they responded to the questions by adding information to the lesson or changing a strategy.

In the NFS's report, Lieberman (1995) describes an approach called Foxfire, which also encourages teachers to use and incorporate students' interests and choices into the lessons. By doing this, teachers involve students in planning and carrying out their own learning (Lieberman, 1995). In this approach teachers are learners as well; both teachers and their students are involved in using learned skills and abilities to identify problems and to seek methods that help them seek answers (Lieberman, 1995).

The second aspect on Irby's (1994) list is the teacher's ability to organize and present medical knowledge in a way that learners can understand and use it so that learning objectives are met. During the clinical learning this often happens in a form of short teaching points, modelling interactions and reasoning processes, and encouraging learners to elaborate and reflect upon their knowledge. This way it is possible to gain the biggest benefit in learning, since the appropriate information is available during the ongoing situation of comprehension (Bransford & Johnson, 1972). In one of Irby's (1994) examples, the students were relieved to receive practical advice that was supported by data, and a model to apply in practice. The doctor in charge of the teaching during that medical case offered both *practical* and *formal* knowledge in the context of dealing with that specific patient.

The last aspect is the aid, which teachers provide to the learner to challenge and expand their existing knowledge (Irby, 1994). In Irby's study in order for this to happen, teachers needed knowledge of medicine, patients, learners, general principles of teaching and case-based teaching scripts. Although the teachers in the study provided a great deal of feedback in general, giving feedback is still a problem during the clinical rotations (Irby. 1994).

The principles of the model agree with both Borko (2004) and Irby (1994) on the importance of a flexible teachers' knowledge base. Although the idea behind the model is to collect and explore the knowledge together with the students, the teacher needs to have knowledge of the topic. Without this knowledge, the teacher is not able to move between the domains and determine when students need more guidance to continue or more knowledge to solve a problem. Both teachers that used the model to teach their lessons had the learning and designing processes under their control but they also adjusted the approach if needed or added something if the situation required it.

The two teachers had collected information and had done research on how to include examples in the lesson. Based on this work their students received, in a similar manner to Irby's (1994), advice based on this research but more importantly, an example to use. Additionally, the teachers were able to challenge their students and answer to their challenging questions.

Until now the problematic nature of too abstract teacher learning models has been discussed. The potential and limitations of the model presented in this dissertation have been reflected to development of other teachers learning aids. It is rewarding to observe similar features in them than what the tests with the model have shown. Next, two studies are presented to have a discussion about the factors needed to be taken in to consideration when new approaches are suggested and taken into a classroom.

7.5. Discussion

"Standards for Technological Literacy" encourages architects, computer scientists and programmers, industrial designers, technicians, draftspersons, equipment maintenance personnel and others to read the document and support its implementation in schools (ITEA, 2007). If this means that parents in those professions get more involved in the matters of their children's schooling, it is a good suggestion. However, it becomes problematic if it means that parents and other people from those professions start teaching technology lessons in schools. Technology itself is not a stand-alone subject; it needs other disciplines in order to exist. One of the ideas of technology lessons is to be able to combine different disciplines and use the knowledge from those disciplines in an applicable way. If teaching responsibility is outsourced to an expert, this overview of different disciplines working together disappears. How do we guarantee that after an expert's visit in the classroom the teacher is able to continue the work where the expert left it? Without certainty that the teachers are able to continue from and include the experts input into their teaching, technology education will stay isolated, just like the school topics are at the moment.

Kangas, Seitamaa-Hakkarainen and Hakkarainen (2013) report a collaborative design project in an elementary classroom where a professional designer provided the leadership. The goal of the study was to get insights on how disciplinary expertise might be infused into design and technology classrooms and how authentic design practices might be included in classroom practice (Kangas et al., 2013). The project was to design a lamp and it lasted for 11 sessions (one session was 45-135 min) during a period of two months. The students designed a lamp with the help of a professional interior designer specialized in lamp and light designing.

The results of this study illustrated that the designer's influence "*opened up the world of designing for the students*" (Kangas et al., 2013). During these sessions, the designer had the domain expert role in the classroom and the teacher's role was to organize the project's timetable as well as tools and materials for the project and to provide support to both the designer and the students (Kangas et al., 2013). The design project lasted more than one or two lessons, which allowed the designer to really show what the profession is about and to give a good idea about designing as well.

The idea of bringing an expert into the classroom to teach topics and offer projects that are similar to real-life experiences is an excellent way to connect school topics to industry and the other way around. On the other hand, if teachers are not actively involved in the process and the teachers do not learn together with the students, the experience with the expert remains as an isolated event again. Using an expert to teach a (design and) technology lesson to students is appealing in many ways since the teacher does not have to find the answers to the discipline specific questions that the expert already knows, students gain experience by doing meaningful projects and the expert gets new challenges and experiences to name a few. Thus, yet again, what does the teacher learn from these experiments and how does this improve technology education in a longer run? The students will gain meaningful experience and most likely also the teacher and the designer. But if technology education becomes series of independent (however, meaningful) experiences, are we neglecting the ideology of technology education being an advocate of crossing discipline boundaries and bridging the gap by combining knowledge from different fields?

Another approach was chosen to boost creativity in design and technology education. At the time of writing this dissertation there was unfortunately no publication available from this study[23], but a publication is in preparation. The following description is based on personal communication between the author and Remke Klapwijk. The email exchange and a phone call took place between June 22 and 26, 2013. Klapwijk is involved in a project of the Wetenschapsknooppunt Zuid-Holland where Industrial Design & Engineering students and primary teachers work together to develop new approaches towards design and technology lessons[24]. The idea behind this project was to give students experience in creative facilitation as well as work as partners with teachers and learn together.

In order to do this, both sources of expertise needed to be involved. The teachers provided teaching expertise, and the students facilitated creativity. The key was in the balance between the roles of the teacher and the student. Klapwijk described that the teacher and the student planned the individual design and technology projects together. The student made the proposal to which the teacher reacted and added his/her ideas or the proposal was made together all the way. These Industrial Design students had no educational background and little experience in teaching all together. Therefore, it was important that both the teacher and the engineering student understood his/her role.

As an example of the importance of the different roles, Klapwijk described a case where the teacher missed the kick-off meeting of the project and thus, felt less prepared to do the project. This had an influence on her attitude, preparation and implementation of the lesson. The Industrial Design student was given almost free hands to execute the project. This did not serve the purpose of the project. Based on this Klapwijk emphasized that both parties have to be willing to learn, to share and cooperate.

During these processes, teachers were actively involved in the lessons and they learned about teaching design and technology from the students and vice versa. The Industrial Design & Engineering students were focused on the tasks and provided authentic experiences to the pupils. When the teacher and the student understand their different but equally important roles, the different approaches add up and a sound didactic approach for teaching design and technology in a way that stimulates creative thinking has been developed[25]. Klapwijk, however, believed that at the time of the correspondence it was too early to say whether these teachers will use creative design in their lessons. Creative design is a new approach that is hardly supported by the Dutch Educational policies and therefore, most likely these efforts remained, at least at the moment, as isolated events. However, involving teachers in co-research and innovation creates ambassadors as well as practical approaches for design and technology.

The point of the above discussion was to explore boundaries of technology education and to see it from the teacher's professional learning point of view. Maybe a discussion as such, raised new ideas and thoughts for future research as well.

In the next section recommendations for future development of the model are given. Also a discussion on what the effect of using the model in teacher preparation education could mean on a larger scale is given.

23 A blog: http://ruimtevoortalent.blogspot.nl, in Dutch.

24 See the blog post: http://ruimtevoortalent.blogspot.nl/2011/09/creatief-ontwerpen-de-kunst-van-het.html, in Dutch.

25 See more: Klapwijk, R. and Holla, E. www.wetenschapsknooppuntZH.nl, in Dutch.

7.6. Recommendations

Educational reform in the United States has lead to the development of new instructional practices such as the No Child Left Behind (NCLB). This policy requires from each state to ensure that “high-quality” professional development is available for all teachers (Borko, 2004). What NCLB does not address is what is meant by this high-quality professional development or how it should be made available to teachers (Borko, 2004).

The publications from the field of science and technology education and this four year research have shown that teachers are the key to any educational reform. However, researchers have to be able to provide tangible, concrete advice to the teachers, and policy makers should allow this to happen. What Klapwijk has started is one step closer to this goal. Teachers’ professional development is about construction of the professional *I*, which evolves throughout teacher’s career and is a complex web of histories, knowledge, processes and rituals (Marcolo, 2009).

Because teachers’ professional development is an evolutionary process, the theory and improved practice need to be brought into the classroom. The only way to do this is to combine university research with practice. At the university, learning models and pedagogical approaches can be explained and translated into the needs of individual discipline. This, however, has to be done in a better way than hitherto. Teachers cannot be expected to read long documents and precise research descriptions on top of conducting classroom management, parent-teacher evenings and naturally, their teaching. This is the job of the researchers. They explain and help to apply the improvements into classroom practice.

Teachers know that in today’s world they have to constantly improve their profession whether they want to do it or not. Studies are promoting student ownership in the learning. If a learner feels that the topic or the approach is suitable for him or her, and the learner can influence on how the learning happens, learning improves as well. This same idea can be extended to teachers. The challenge, which naturally follows when suggested improvements are brought into the classroom, has to be manageable and within the teacher’s reach though.

Teachers of all levels and disciplines, not only in science and technology, would benefit from non-linear thinking and collective approaches to teaching and learning. Non-linear thinking is the type of thinking that the model emphasizes. Topics and concepts communicate and intervene. The difficult questions, concepts and topics are a chance to learn and explore, instead of them being hurdles to climb over.

Similar idea applies to collective approaches in teaching and learning, where the information and knowledge is collected together. This does not only apply to teachers and students in classrooms at a specific time. Teachers can collect knowledge together with students, with a researcher or just among themselves. This way, a teacher, whose approach is more research orientated will help to develop technology education and other school topics. The improvements have to be focused and right goals need to be made clear before they are brought into the classrooms. Else even the most motivated teacher will not be able to work with the researcher nor implement the wanted ideas.

Furthermore, a different approach stems from everyone’s own education, when teachers are still yet to become teachers. At tertiary level, students (hopefully) focus on the disciplines of their liking and they want to become experts of that specific field. What the industry needs affects the outlines of these disciplines and the topics taught to the students, in addition to the fundamental concepts of each discipline. These needs come directly from customers and markets, which the industry is carefully listening to. Due to this chain of needs, the content of each discipline is under constant revision and change. Especially in fields like computer science, electrical engineering, information technology et cetera, colleges and faculties have become aware of the fact that students need to have a clearer idea of the social and ethical aspects of their studies as well. This by no means is a bad decision; knowledge of moral dilemmas in engineering, the impact of technology on society and the environmental aspects of an engineering project are concepts that today's students need to consider.

However, on tertiary level a vast amount of information needs to be taught by lecturers and learned by students. The current way of teaching is to dedicate courses on matrix calculation to computer scientists, algorithmic thinking to electrical engineers and so forth. Then the topics that relate these specific disciplines to ethical issues or current market trends are covered in free elective courses.

It does not matter how aware teachers at the tertiary education are about providing a clear and up-to-date view on the discipline if the implementation is such as described above. The students take these courses because they must. They may be passionate about their study and any variation from the main topic is a distraction and feels forced. Also extra-curricular studies are away from free time or studying what really is interesting. The problem is not solved either by asking a lecturer to include another aspect such as ethics or morals to his/her lecture. Doing this asks more planning from the lecturer and the attitude might be the same as the students'; it is just a free elective, the actual topic is more important and the addition is just not worth the trouble.

Therefore, even within courses at the beginning of the tertiary education, students should get used to thinking in a broader way. Teachers that already provide to their students aspects from marketing and energy efficiency on their theoretical computer science courses should be encouraged and shown as an example. Threading the concepts to other disciplines and related issues might help to learn the concept, remember discipline-specific knowledge and avoid 'misconceptions'. Teaching a theoretical computer science concept by using an example from marketing might sound counterintuitive. This, however, combines a concept with a concrete aspect and might be what is needed to help students see their thoughts in a broader perspective. Maybe this also helps lecturers on tertiary education see the real importance of what they are teaching and help them sharpen their lectures.

The approach that the model offers to science and technology, address these issues. The research around it is far from complete but the model itself provides an appealing proposition. It is based on research; it brings the teacher's learning process into the classroom; it allows autonomy to the teacher but at the same time keeps the possibility for a dialog with both research and students open. The model seems to reach pupils as well and it is applicable to larger educational tasks as well as to individual classes.

The context, in which this study took place, presents us with an interesting dilemma. On one hand, the teachers in the in-service teacher training were the ones that belong to majority of how primary teachers in the Netherlands are. On the other hand, the teachers that the author had a privilege to work with, when testing the model, were the ones that the teachers in the Netherlands should be like.

Technology education in primary schools would benefit from having more teachers such as the ones testing the model. Training teachers to have such an approach towards their own profession and teaching, needs to start when the teachers are still students. Future primary teachers have to have, in their training, courses that teach them research-type of mindset to teaching. With research it is not meant here that it has to be a year-long investigation; it simply refers to the type of approach towards teaching. This type of mindset can be introduced to the student teachers with the help of the model by collecting information about science or technology concepts combined to one another. The best way of starting this process is to assign concepts, like the ones presented in this dissertation, to the future primary teachers and let them investigate, collect and combine information to come up with a framework for a full lesson. At first this can happen together as a whole class and later one, each individual student teacher can prepare a lesson of their own. After this, the student teachers would teach a lesson based on their investigation, and their peers as well as the trainer would ask questions and evaluate the test lesson. The evaluation should not only include peer reviews of the lesson. The student teacher, who taught the lesson, should also give feedback in order to see whether using the model helped to prepare a lesson.

Before student teachers can use the model as an aid in their studies, their trainers need to be made familiar with it as well. This asks help from organizations, such as former KWT-West, that can train the trainers. This naturally requires funding and proper facilities. One successful, small scale example of such a professional development activity was presented in this dissertation. Ideally, the teacher trainers are offered professional development activities, where one of the assignments is to learn and teach with the help of the model. Every teacher trainer is shown how to prepare a lesson by using the model. After this, the teacher trainers return to their institutes and teach such a lesson. These professional development activities should not only offer new ideas and approaches but they need to include discussions with peers as well. Besides learning how to use the model, the participating teachers should be encouraged to share their ideas, opinions and materials as well as discuss about the approach and difficulties of it. Both teachers and research benefit from this type of input.

Involving research orientated organizations in to the process means that the model can be tested and developed further. Although the preliminary tests presented in this dissertation support the fact that the model could work in practice, further research is needed. As informative as qualitative research can be, the model needs to be tested in quantitative ways as well. Testing the model with larger data samples is necessary in order to prove that the suggestion that the model offers works. The research of this kind can be started by teaching the teacher trainers first. This should be followed by observation in their home institutes when they present the model to their student teachers. Even though quantitative research methods are needed to test and develop the model, observation and interview are useful data collection methods at this point as well. During the actual lessons, the way the model is applied, requires observations. Recording verbal feedback is more time consuming but through interviews teachers can express their opinions and feelings concerning the model in an easier way than writing it all down.

After studying the teacher trainers, the focus can be shifted to the future primary teachers. The student teachers need to be tested to see if the model had the wanted effect on them. These student teachers then can prepare a lesson of their own with the help of the model. The test lessons need to be recorded and evaluated as well. Eventually, the student teachers need to be followed to their classrooms to observe how the model is applied and how the pupils respond and learn the concepts taught.

By including (student) teachers and their classrooms into the research, the actual value of the model can be measured. With both of these groups, a pre- and post-tests concerning the science and technology concept knowledge can add valuable data in to the model development as a whole.

If the quantitative research shows that primary teachers are more prepared to teach science and technology and their own concept knowledge of these two topics has improved, it seems that the approach of the model is towards the right direction. If the teachers show improvement, this should be related to how their pupils perform as well. As a goal, the pupils should be able to demonstrate improved science and technology concept knowledge. This can be ultimately tested by having tests on a national level that include questions that examine knowledge of the same concept in various contexts.

And what should the position of concept learning in primary science and technology education be then? It deserves a place in every topic dealt with in science and technology lessons. Of course science and technology education on a primary level should be about designing, experimenting and getting the first rendezvous with the topic. However, each science and technology lesson or series of lessons should have a purpose. Often pupils end up merely creating and the actual learning goal tends to be forgotten. Technology lessons are considered to be successful as long as pupils are doing something and they are having a good time. If every lesson has a core concept to be learned, the goals are easier to set and the purpose of the lesson stays clearer in mind.

According to the English Department of Education (2013), Design and Technology (D&T) on Key Stages 1 and 2 should include, besides the core ideas, cross-curriculum references. These references list noteworthy core concepts, such as materials and objects (hardness, strength, flexibility and magnetic behaviour), standard units of length, mass and capacity, forces and motion as well as electricity etc. This list of concepts could be used as an example in any primary science and technology education curriculum or lesson planning. Probably concept of systems and some basic programming (algorithmic thinking) might be useful to learn as well.

All in all, science and technology education should start in primary schools and its implementation should start from the teachers. This goal needs to be made clear in the teacher training programs as well. Hopefully this dissertation has given ideas and suggestions for future research to aim towards that goal.

"Nothing in life is to be feared, it is only to be understood."

Marie Curie

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Summary

Technology is strongly present in today's society and some of the technological artifacts have become so familiar to us that we hardly recognize or even think of them as such. We cannot think about our lives without any technological artifacts or inventions in it. In order to understand our dependency on technology and the possible loss of control that comes with it, it is necessary for people to understand the nature of technology as well as its roots in science. OECD (2006) states that as a citizen some understanding of science disciplines is required to be able to participate in society and control one's own life. Many countries have updated their curricula to answer this demand and schools have subjects concerned with technology education.

It appears that science and technology education has an important role in primary education. However, it hardly exists in the Netherlands, and internationally the situation is not much better, except in England, Wales and New Zealand.

Learning basic science and technology concepts should be a part of primary education since it gives children the first understanding of the natural and artificial world around them. Including basic science and technology concepts in to primary education introduces these concepts gradually as well. Later on, in secondary education, children learn the same concepts but the level of abstraction is much higher.

According to Piaget, children only from 12 years on are able to think in terms of concepts (Woolfolk, Hughes, & Walkup, 2008). However, research has shown that young children are able to form causal presentations (Gopnik, 2012; Van Oers & Poland, 2012) and schools constantly acquire abstract thinking from young pupils in a form of mathematical operations and grammatical parsing (Van Oers & Poland, 2012). Thus, as long as the level of abstraction is kept suitable for young pupils; meaning no formalization should be expected, concept learning seems to be possible even on the primary level.

Despite the above mentioned benefits, concept learning in primary science and technology education has hardly been the topic of research. Concept learning of primary teachers has not been investigated largely either. In the Netherlands, attempts towards introducing in-service teachers to concept-context learning through a professional training have been done e.g. the VTB-program. The fundamental idea behind this program was that in order to address science and technology topics in everyday classroom situations, primary teachers have to develop their knowledge, attitudes, and inquiry skills within science and technology in an exploratory and reflective manner (Walma van der Molen et al., 2007).

In this dissertation a problem with respect to the above argumentation will be shown and a possible solution with preliminary testing will be offered.

The study is qualitative and the interest is twofold. Firstly, the knowledge of *science* concepts of *primary teachers* and *student teachers* as well as knowledge of *technology* concepts of *pupils* was investigated. To obtain this knowledge, three studies were performed using pre- and post-lesson assignments and observations. Based on the findings, it appears that certain parameters, such as science 'misconceptions' and lack of cause-effect type of thinking, influence on how science and technology concepts are taught and learned.

This introduces us to the second part of the study. To suggest an improvement to the current

situation, a model to assist teaching and learning of science and technology concepts was proposed and a preliminary test of the model was performed.

The research started with the study presented in Chapter 1. The study investigated primary teachers' knowledge of science concepts related to air and water. The data was collected mostly by means of pre-lesson assignments. The analysis is based on the answers but observations made during the training are taken into account as well.

In Chapter 1 it is argued that the teachers have various pre-concepts that do not match with the ones used and taught in science and technology. These pre-concepts exist for a reason and they help teachers to deal with practical situations in a successful way. But these 'facts' remain limited to a particular situation. Furthermore, the analysis revealed that one of the shortcomings in the observed in-service teacher training activity was that the method used does not provide enough support for teachers to connect a concept to its practical application. In fact, post-training assignments showed that the teachers had not comprehended what they learned; it is therefore, unlikely that these concepts will be used in practice. Therefore, extra attention needs to be given on describing the concepts in a way that an understanding can emerge within the teachers.

The issues, to which a relatively short professional training cannot offer a solution, suggest that teachers' views on teaching and learning science and technology can be a result of their pre-service education. Therefore, Chapter 3 continued to examine science and technology concepts of students studying to become primary teachers.

The second study revealed that the student teachers have a tendency to link the concepts to tangible properties, in a similar manner to the in-service teachers in the previous chapter. The analysis showed that they were able to provide an answer to the post-lesson questions if the trainer's example corresponded exactly to the question. Without a concrete example of the concept, a relatively small change between pre- and post-lesson results was seen.

These two studies have shown that both in-service and student teachers lack understanding. They cannot make a connection between the concepts and the practical situation. To broaden the view on science and technology education and to see what the situation in classrooms is; a study presented in Chapter 4 was conducted. This study examined teaching of systems concept to young pupils.

The study showed that pupils did not consider the concept of feedback in a system, and the emphasis was on experience gained by using such a system. Pre-lesson assignments showed that the concept of input is more obvious to the pupils than the concept of output. However, post-lesson assignments showed that the most noticeable change had happened with respect to outputs as the latter were more present in pupils' answers. Furthermore, the systems used were described in terms of what a user can do and experience while using such a machine. In these cases, the tasks of a user and a machine overlapped and it made setting the system boundaries more demanding.

These results are promising. However, choosing the right approach asks more planning from the teacher than might appear at first. Teachers need to be attentive to how they can make pupils understand concepts. As recommended in Chapter 4, the learning of systems thinking should start by using systems that are already familiar to pupils.

The first two studies gave an impression that teachers require help in forming an explanation and thinking in terms of cause and effect. Additionally, pupils' user-driven approach to systems hid underlying concepts, and the focus was only on what could be seen and experienced by using the system. It seems that an aid that helps teachers towards cause-effect reasoning and coherent argumentation is needed.

The model presented in Chapter 5 tackles these issues. It provides an aid for teachers to plan and teach science and technology lessons. It combines and connects practical and abstract knowledge throughout the learning process.

This model distinguishes three domains: the social context, the concrete product and concepts. Learner's preference for tangible properties of concepts is addressed by including the concrete object domain in the middle of the model. This domain connects contextual and conceptual understanding through artifacts. Furthermore, the model connects theory and practice with social context that makes sense in that learning moment. The use of these domains provides boundaries to the lesson but also flexibility to give room to creativity.

The model is tested in a micro-situation and this is presented in Chapter 6. Two teachers used the model to plan a lesson or a set of lessons. Based on this study and the feedback from the teachers, the approach offers a candidate to be considered in order to help teachers to teach and learn concept-context learning. During the planning the teachers worked with the model to collect the required information with the help of domains of the model. This also prepared them to answer to the questions their students had during the learning process. When faced with a problem of how to explain student questions, movements between the domains helped them to choose an approach.

When reading this dissertation it should be kept in mind that the research was set up to find *phenomena* related to the teaching and learning of science and technology concepts in primary education. The observations from the studies, although qualitative, do suggest that the model offers the needed help and a change can be accomplished among primary teachers. The suggested improvements are based on the observations from the three studies, and therefore, they are only preliminary suggestions and need to be further investigated. Therefore, the results cannot be generalized at this point yet.

The chapters follow their original outline and appearance as much as possible, the published articles and book chapter have been revised for this dissertation though. This is done only to make the chapters more coherent and to avoid duplication. The reason for changes is to make the dissertation more readable as a book.

Samenvatting

In de hedendaagse samenleving is de techniek nadrukkelijk aanwezig en sommige technische artefacten zijn zo vertrouwd voor ons dat we ze nauwelijks meer als zodanig zien of herkennen. We kunnen ons het leven niet voorstellen zonder technische artefacten. Om onze afhankelijkheid, en een mogelijk verlies aan beheersing dat daarmee gepaard gaat, te begrijpen, moeten mensen de aard van de techniek en de wetenschappelijke achtergronden ervan begrijpen. De OECD (2006) stelt dat elk burger enig begrip van de wetenschappelijke disciplines moet hebben om in de samenleving te kunnen participeren en zijn eigen leven onder controle te hebben. Veel landen hebben hun curricula gemoderniseerd om op deze behoefte een antwoord te geven en scholen hebben vakken over techniek.

Het lijkt erop dat wetenschap en techniek een belangrijke rol spelen in het basisonderwijs. Maar toch is het er nauwelijks, in Nederland, en n het buitenland is het niet veel beter, behalve in Engeland, Wales en Nieuw-Zeeland.

Het leren van basisbegrippen uit wetenschap en techniek zou onderdeel van het basisonderijs moeten zijn omdat het kinderen een eerste inzicht geeft in de natuurlijke en artificiële wereld om hen heen. Door al in het basisonderwijs de basisbegrippen van wetenschap en techniek te introduceren, kunnen ze geleidelijk zich ontwikkelen. Later, in het voortgezet onderwijs, kunnen leerlingen die begrippen op een hoger abstractieniveau leren.

Volgens Piaget kunnen kinderen pas vanaf hun twaalfde jaar in abstracte begrippen denken (Woolfolk, Hughes & Walkup, 2008). Onderzoek heeft echter aangetoond dat ook jonge kinderen in staat zijn causale voorstellingen te maken (Gopnik, 2012; Van Oers & Poland, 2012) en scholen vragen voortdurend abstract denken van jonge leerlingen in de vorm van rekenkundige bewerkingen en grammaticale ontleding (Van Oers & Pland, 2012). Op die manier lijkt begripsleren ook op het laagste niveau mogelijk, zo lang het niveau van abstractie past bij jonge leerlingen en geen formalisering vereist wordt.

Ondanks de bovengenoemde voordelen is begripsleren in het wetenschaps- en techniekonderwijs in basisonderwijs nog nauwelijks onderzocht. Dat geldt ook voor begripsleren bij leerkrachten. In Nederland is gepoogd door nascholing leerkrachten bekend te maken met concept-context leren in het kader van het professionaliseringsprogramma VTB-Pro. De basisgedachte achter dit programma was dat leerkrachten op een verkennende en bezinnende manier kennis, attituden en onderzoeksvaardigheden moeten ontwikkelen om onderwerpen van wetenschap en techniek in de dagelijks klassenpraktijk in te kunnen brengen (Walma van der Molen et al., 2007).

In dit proefschrift wordt een probleem ten aanzien van de bovenstaande argumentatie belicht en wordt een mogelijke oplossing geboden met een eerste toetsing daarvan.

Dit onderzoek is kwalitatief van aard en het belang is tweeledig. In de eerste plaats is de kennis van wetenschappelijke begrippen bij basisschoolleerkrachten en aanstaande leerkrachten onderzocht, evenals de kennis van techniekbegrippen bij leerlingen. Om deze kennis te verkrijgen zijn drie studies uitgevoerd, waarbij gebruik gemaakt is van opdrachten voor en na de lessen en van observaties. Op basis van de uitkomsten, blijkt dat bepaalde parameters, zoals ‘misverstanden’ over wetenschappelijke begrippen en een gebrek aan oorzaak-gevolg denken, van invloed is op de manier waarop wetenschap en techniek worden onderwezen.

Dit brengt ons tot het tweede deel van de studie. Daarin wordt een model om het leren van wetenschappelijke en technische begrippen te ondersteunen geïntroduceerd om deze situatie te verbeteren, en een eerste toetsing van het model heeft plaatsgevonden.

Het onderzoek begint met de studie die in hoofdstuk 2 wordt gepresenteerd. In deze studie wordt de kennis van leerkrachten ten aanzien van begrippen rond lucht en water onderzocht. De data zijn voornamelijk verzameld aan de hand van lesopdrachten. De analyse is vooral gebaseerd op de antwoorden, maar ook zijn tijdens de trainingen observaties verricht.

In hoofdstuk 2 wordt betoogd dat leerkrachten verschillende preconcepties hebben die niet passen bij de begrippen die onderwezen worden in wetenschap en techniek. Die preconcepties zijn er om een bepaalde reden en helpen de leerkrachten om situaties in het dagelijks leven met succes te duiden. Maar ze zijn beperkt tot bepaalde situaties. Verder liet de analyse zien dat een tekortkoming van de waargenomen trainingen in de nascholing van leerkrachten hen niet voldoende ondersteunt om begrippen te verbinden met praktische toepassingen. In feite lieten de opdrachten na afloop van de trainingen zien, dat ze zelfs niet eens begrepen hadden wat ze geleerd hadden; darom is het onwaarschijnlijk dat ze daarna de begrippen in de praktijk gaan gebruiken. Het is daarom nodig extra aandacht te geven aan het beschrijven van die begrippen op een zodanige manier dat echt begrip bij de leerkrachten kan ontstaan.

Deze kwestie, waarvoor een relatief kortdurende training geen oplossing kan bieden, suggereert dat de visie van leerkrachten op wetenschap en techniek het gevolg is van de initiële opleiding die ze gehad hebben. Daarom vervolgt hoofdstuk 3 met een onderzoek naar wetenschappelijke en technische begrippen bij aanstaande docenten.

Deze tweede studie laat zien dat de leerkrachten-in-opleiding de neiging hebben om begrippen te verbinden met tastbare eigenschappen, net als de leerkrachten in het eerste onderzoek. De analyse liet zien dat ze een antwoord kunnen geven op een vraag in de vragen na afloop van de lessen mits het voorbeeld van de trainer precies past bij de vraag. Zonder concreet voorbeeld bij een begrip is er maar weinig verschil te zien tussen de resultaten voor en na de les.

Deze twee studies laten zien dat zowel zittende als aanstaande leerkrachten een gebrek aan inzicht vertonen. Ze kunnen geen verbinding leggen tussen begrippen en praktische situaties. Om het beeld van wetenschap en techniek te verbreden en te zien wat er in de klas gebeurt, is een studie verricht, die in hoofdstuk 4 wordt gepresenteerd. In deze studie wordt het onderwijzen van het systeembegrip aan jonge kinderen onderzocht.

Deze studie liet zien dat leerlingen het begrip terugkoppeling in een systeem niet onderkennen, en dat de nadruk lag op ervaring met het gebruik van zo'n systeem. Opdrachten voorafgaand aan de lessen lieten zien dat leerlingen makkelijker het begrip input dan het begrip output herkennen. Opdrachten na afloop van de lessen lieten echter zien dat de meest opmerkelijke verandering had plaatsgevonden ten aanzien van de output, omdat dat laatste het meest in de antwoorden van leerlingen terug te vinden was. Verder werden systemen voornamelijk beschreven in termen van wat de gebruiker er mee kan doen en van ervaringen in het gebruik van de machine. In zulke gevallen overlapten wat de gebruiker doet en wat de machine doet en was het lastiger de systeemgrenzen aan te geven.

Deze resultaten zijn veelbelovend. Maar om de juiste benadering te kiezen vraagt meer planning van de leerkracht dan aanvankelijk leek. Leerkrachten moeten goed opletten hoe ze leerlingen kunnen helpen bij begripsvorming. Zoals aanbevolen wordt in hoofdstuk 4 moet het leren van het systeembegrip beinnen bij systemen waarmee de leerlingen vertrouwd zijn.

De eerste twee studies wekken de indruk dat leerkrachten ondersteuning nodig hebben bij het ontwikkelen van verklaringen en het denken in termen van oorzaak en gevolg. Daar komt bij dat de gebruikers-gedreven benadering van leerlingen ten aanzien van systemen onderliggen de begrippen verborgen houdt en dat de nadruk ligt op wat te zien is en ervaren wordt bij het gebruik van systemen. Het lijkt erop dat een hulpmiddel nodig is om leerkrachten te ondersteunen bij het redeneren in oorzaken en gevolgen en bij het geven van een samenhangende redenering.

Het model in hoofdstuk 5 pakt dit aan. Het biedt een hulpmiddel voor leerkrachten om lessen over wetenschap en techniek voor te bereiden en uit te voeren. Het brengt praktische en abstracte kennis bij elkaar in het hele onderwijsleerproces.

Het model onderscheidt drie domeinen: de sociale context, het concrete product en begrippen. Door het concrete object centraal te stellen in het model wordt voldaan aan de voorkeur van de lerende van tastbare eigenschappen. Dit domein verbindt begrip van de context en van de begrippen dor middel van artefacten. Verder verbindt het model theorie en praktijk met de sociale context, hetgeen in dat leermoment zinvol is. Het gebruik van deze domeinen houdt de lessen binnen zekere perken, maar biedt tegelijk flexibiliteit om ruimte te geven voor creativiteit.

Het model is getoetst in een micro-situatie en dit wordt in hoofdstuk 6 gepresenteerd. Twee leerkrachten hebben het model gebruikt om een les of een lessenserie te plannen. Op basis van deze studie en de terugkoppeling van de leerkrachten, lijkt deze benadering het verder verkennen waard te zijn om leerkrachten te helpen bij concept-context leren. Tijdens de planning werkten de leerkrachten met het model om informatie te verzamelen aan de hand van de domeinen in het model. Dit hielp hen tevens om vragen die leerlingen tijdens de lessen hadden, te beantwoorden. Als ze geconfronteerd werden met een probleem bij het uitleggen van vragen van studenten, hielp het heen en weer bewegen tussen de domeinen hen om een benadering te vinden.

Bij het lezen van dit proefschrift is het goed te bedenken dat het onderzoek alleen het bestaan van bepaalde verschijnselen met betrekking tot het leren en onderwijzen van wetenschap en techniek in het basisonderwijs aantoont. De waarnemingen in de studies suggereren, hoewel ze slechts kwalitatief zijn, wel degelijk dat het model hulp kan bieden en dat het leerkrachten in het basisonderwijs kan veranderen. Deze ogenschijnlijke verbeteringen zijn gebaseerd op waarnemingen in de drie studies en zijn daarom slechts voorlopige aanwijzingen die verdere bestudering behoeven. Generalisering is hier nog niet mogelijk.

De hoofdstukken staan zo veel mogelijk in hun oorspronkelijke verloop. De reeds gepubliceerde studies zijn echter herschreven voor het proefschrift. Dit is gedaan om het geheel meer coherent te maken en overlap weg te nemen. Het motief was dus om het proefschrift als boek leerbaarder te maken.

Curriculum Vitae

Marja-Ilona Koski (born 15th of April 1982 in Kuopio, Finland) started the three-year secondary education (high school) on the academic track (lukio) in Kuopion klassillinen lukio in August 1998 and finished in June 2001. On that same year, in September 2001, she started studying at the university.

She studied computer science and pedagogy at the University of Helsinki. She received her master's degree in computer science (teaching track) in May 2008. In her pedagogical studies for teachers she received the highest grade (5/5) from her joint research project on teaching computer science concepts to young pupils.

Parallel to her studies she has worked as a research assistant at the Centre of Educational Assessment, University of Helsinki, Finland. She has corrected Finnish pupils' answers to science questions in the PISA exam. And she has been a substitute teacher at the basic comprehensive technology school of Aurinkolahti, Helsinki, Finland, where she taught math, computer science, technology, physics and mechanics.

In June 2009 she started her PhD research project at the Technical University of Delft, in Science Education and Communication research group.

Appendix A

Questions for the topic ‘Air’

Question 1: Describe what is air?

Question 2: Eve has two identical 1 litre glass bottles. She weighs them on a scale. After this she fills one of them with air and she makes the other one into a vacuum. Then she weighs the bottles again. On the scale she sees that:

- ❑ Adding or removing air doesn’t change the weight.
- ❑ The bottle that is a vacuum weighs more.
- ❑ The bottle that is filled with air weighs more.
- ❑ Both of the bottles weigh the same because they are the same.

Question 3: Pete has five books of Dostoevsky on top of a swimming ring. He starts to blow air into the ring. After a while, what will happen? Is it possible with this technique and with this ring to lift the books? Explain why **yes** or **no**.

Question 4: Two balloons equal to size are held in hand as shown below? Explain what makes the following situation possible and why?

Question 5: When a balloon rises, what happens to the air pressure around the balloon?

- ❑ It becomes *more* than at the ground level.

- ❑ It becomes *less* than at the ground level.

Question 6: Why does air cool down when it rises?

- ❑ As the air rises, it cools down because *the atmosphere higher up is colder*.

- ❑ As the air rises the air pressure becomes *higher* and this cools down the air.

- ❑ As the air rises the air pressure becomes *less* and this cools down the air

Question 7: The wings of an airplane are designed in such a way that the upper side of the wing is curved and the bottom side is almost straight. This means, according to the Bernoulli's principle, that within the same time air has longer distance to travel on the upper side of the wing than on the below. According to this same principle it creates a lift but why?

- ❑ More air floats on top of the wing creating a high pressure needed for the lift.
- ❑ Air floats slower on top of the wing due to the longer distance and this creates high pressure needed for the lift.
- ❑ More air floats on the bottom of the wing creating a high pressure needed for the lift.
- ❑ Air floats slower on the bottom of the wing to balance the difference compared to the top part and this creates high pressure needed for the lift.

Appendix B

Questions for the topic 'Water'

Question 1: Describe what is water? (Focus on the nature of water, not on what you can do with it.)

Question 2: How is it possible that a boat made out of iron *doesn't sink*?

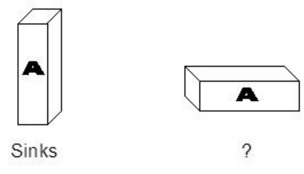
Question 3: A child is playing with toy boats in a bathtub. One of the bigger boats is filled with heavy toy building blocks. What happens

a. to the boat

b. to the water level

when the child starts to unload the blocks into the water? Can the water come over the bathtub edge on to the floor?

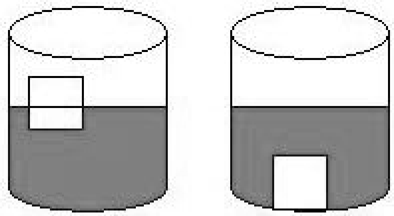
Question 4: Block A *will sink* if it is placed in the water as shown *on the left*. If it is placed in the water as shown on the right what will happen?



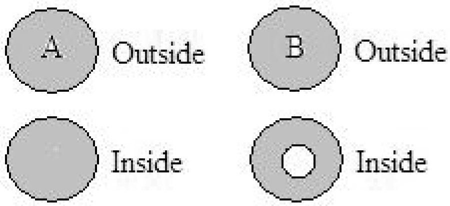
❑ It will sink.

❑ It will float.

Question 5: Dave has two glasses filled with liquid as shown below. He drops one ice cube (both cubes are equal in size) into each glass. Why does the following situation occur?



Question 6: These two balls have the *same mass* and the *same volume*, but they are made from different materials. Ball A *will sink* in water. What happens to ball B when placed in water?

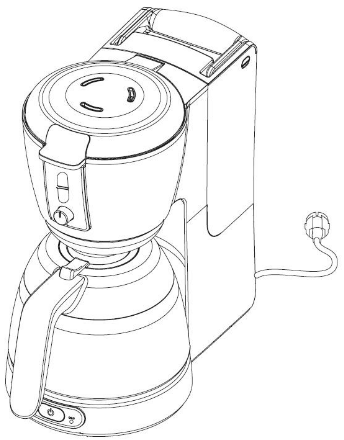


❑ It will sink.

❑ It will float.

Question 7: Below you see a picture of Philips coffee maker and instructions on how to brew coffee.

a. Which elements in the prescription/picture affect on each other,
b. What types of influences can come from outside the system and how do they affect on the system (coffee maker), and
c. What kinds of processes (situations, changes) occur within the system?



1 Make sure the plug is in the wall socket.

2 Make sure the glass jug or thermos jug (with the lid in the 'closed/brewing' position r) is under the filter holder.

3 Set the coffee strength you prefer with the Aroma Control knob.

To increase the coffee strength, turn the knob to the right. To decrease the coffee strength, turn the knob to the left.

4 Remove the water tank and fill it with fresh, cold tap water.

5 Put the water tank back onto the appliance properly.

The Aroma Control indicator moves upwards.

6 Take a paper filter (type 1x4 or no. 4) and fold the sealed edges to prevent tearing and

7 Open the filter holder lid and put a paper filter in the filter holder.

8 Put pre-ground coffee (filter-fine grind) in the filter until the Aroma Control indicator is in the OK position and close the filter holder lid.

9 Press the on/off button to switch on the appliance.

The red power-on light goes on.

10 When all the water has passed through the filter, you can remove the jug from the appliance.

If you remove the jug for more than 30 seconds before all the water has passed through the filter, the filter may overflow.

The coffee is kept hot on the hotplate as long as you leave the appliance switched on.

11 Press the on/off button to switch off the appliance after use.

The appliance switches off automatically after 2 hours.

12 Remove the filter holder

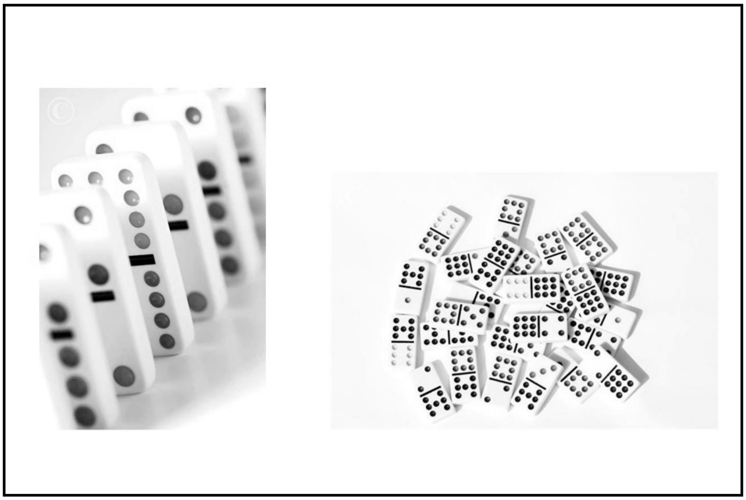
13 Throw away the paper filter.

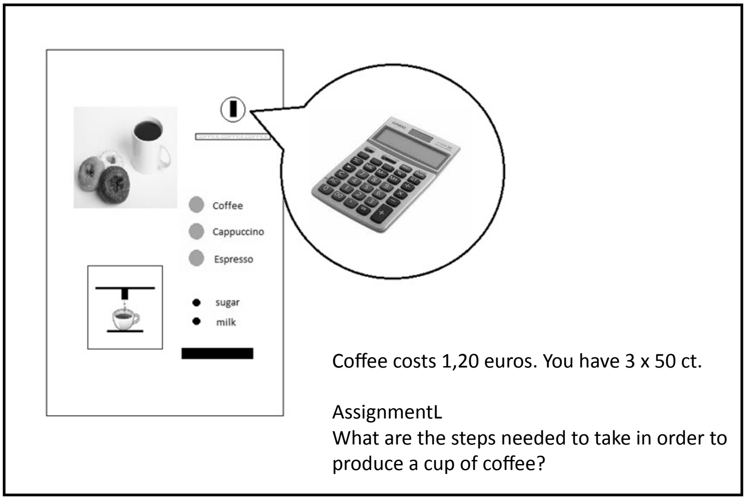
14 Let the appliance cool down for at least 3 minutes before you start brewing coffee again.

http://www.p4c.philips.com/files/h/hd7686_90/hd7686_90_dfu_fin.pdf

Appendix C

Images and questions used as a backbone for a discussion with the teacher about systems and systems thinking.





Producer

Consumer

Market

Reinforcing feedback.

In systems thinking reinforcing feedback (or positive feedback) can be defined as following:

> "***Changes in the system feed back in such a way as to amplify the change, leading to more change in the same direction. Reinforcing feedback amplifies growth.***"

O'Connor, J. and McDermott, I. (1997). *The Art of Systems Thinking – Essential skills for creativity and problem solving*, Thorsons, London.

Can you think of a situation from every-day life, in which this theory could be applied? Or where a situation like this occurs?

Appendix D

Backbone for questions asked from the experienced teacher (face-to-face) and the student teacher (through email and over the phone) in the evaluation phase.

1) What was the main learning goal of the lesson(s)? (e.g., to teach Newton's second Law.)

2) What were the aspects of this topic (e.g., the main applications 1, 2, 3, 4 and 5 where the Law is used etc.) that you focused on? Can you make a list of topics you wanted to cover?

3) How did you integrate these topics to your lesson plan (e.g., the Law is learned based on the method X and exercises, and a lab exercise will demonstrate the application 2)?

4) How well were you able to follow your plan? Were there parts that you skipped? If yes, which ones and why?

5) How did you use the 3D model to plan the lesson?

6) Did the model help you when planning the lesson? If yes, how?

7) Did it bring something new to your usual approach? If yes, what and how?

8) Were you able to use the model (the domains and the connections) in your teaching/ during the lesson?

9) Did the use of the model provide you more confidence to give the lesson? Did you feel more prepared?

10) Do you think the pupils benefited from the approach you chose?

11) Something you want to add?