Testing the three-domain model for science and technology concept learning[1]

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Helping teachers to move away from a 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 paper wants to explore. In this paper preliminary tests of a model designed to help teachers' plan and teach concepts in science and technology education is presented. The three-domain model (Koski, Klapwijk, & De Vries, 2011) suggests that while teaching science and technology lessons, teachers would benefit from paying more attention to three domains; social context, concrete object and abstract knowledge, and furthermore, constantly moving between these. Although Koski, Klapwijk and De Vries (2011) based the development of the three-domain model on real teaching situations, however, it is not self-evident that the model can be used as such in practice.

Two teachers tested the model in their classrooms 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 lessons. Analysis showed that the teachers kept on looking for appropriate moments to bring more insights to the topic and these moments would have missed without thinking in terms of the model. The model helped the teachers to seek for opportunities for the students to communicate their understanding as well. The use of the model introduced them to a non-linear teaching method and to the profits of applying such. The study concludes that both of the teachers benefited from using the model; in their preparation of the lesson as well as during the lesson.

Teachers' professional learning

To form an idea of 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

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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. Chikasandra, Ortel-Cass, Williams and Jones (2013) e.g. 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 open-ended design challenges to a structured, lengthy curriculum programs (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.

Description of the three-domain model

In the following, a short description of the three-domain model and the ideas behind it are presented. The model was first presented by Koski, Klapwijk and De Vries (2011) and the full research and literature study behind the development of the three-domain model can be found in their article.

To support concept learning in real-life like situations, in which abstract and practical knowledge are combined deserves more attention in science and technology education. It is suggested that this is done by using the dual nature of products (Koski, Klapwijk, & De Vries, 2011). Most authors (e.g., Wenham 2005; Rocard & Csemely et al., 2007) emphasise only two knowledge domains (asking what and why -questions refers to combining concrete object and abstract knowledge, and concept-context approach teaches abstract concepts in different (social) settings), but it appears that three domains need attention (Koski, Klapwijk, & De Vries, 2011). Therefore, a three-domain model (from now on a model) for concept learning that supports both the design process as well as concept learning was introduced. The model visualizes important factors in the design process and describes how to emphasise teaching and learning of concepts in specific contexts.

In the first part of the model, the learning process has been divided into three domains; social context, concrete object and abstract knowledge (Figure 1). The first domain provides the social context for learning. The next domain is about concrete objects, where 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 engineering sciences. Concepts from natural science are even more abstract.

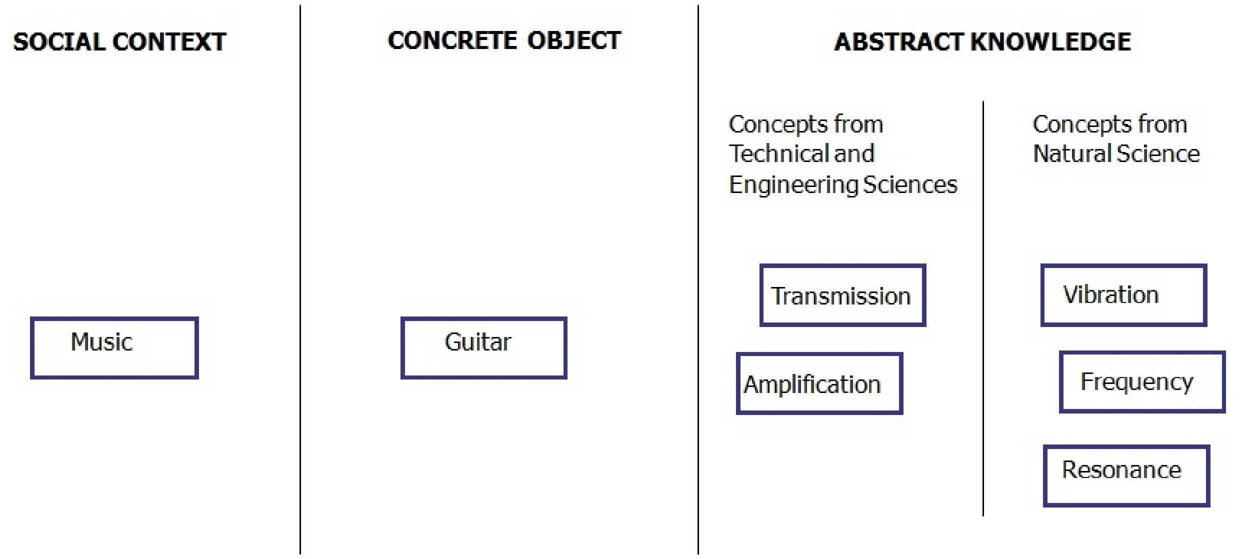


Figure 0. Three-domain model for concept learning; music as an example (Koski, Klapwijk, & De Vries, 2011).

In the first domain the learner is confronted with real-life problems, e.g., a music instrument that is broken. Therefore, the social domain provides the right context to intrigue and trigger the learner into studying the social context, concrete objects and concepts (Koski, Klapwijk, & De Vries, 2011). This domain can be compared Vygotsky's social context.

In the next domain the learner is confronted with objects such as products, materials, tools and hands-on experiments (Koski, Klapwijk, & De Vries, 2011). 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 (see more e.g., De Vries, 2005).

This idea of products having a dual nature makes them interesting because on one hand they can be brought into a classroom. Products can be touched and examined during the lesson 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.

In the next domain, the abstract knowledge domain, the explanations and the relevant abstract concepts are explored (Koski, Klapwijk, & De Vries, 2011). 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 learning in the other domains.

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 abstract 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 as well. 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.

Design of the study

The model emphasises combining and connecting practical and abstract knowledge throughout the learning process. The model can be combined with different pedagogical strategies in teaching; e.g. relations between the knowledge can be introduced in different orders, depending on the level of education. This paper 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.

To examine if the model can meet its expectations, a question to direct the design and execution of the study was formed:

> Is there a feasible set-up for the three-domain 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 (see Figure 2). In this paper the adjusted design of the study is presented. The study and the data were, therefore, divided in to two sub-studies; one with a student teacher and the other one with an experienced teacher.

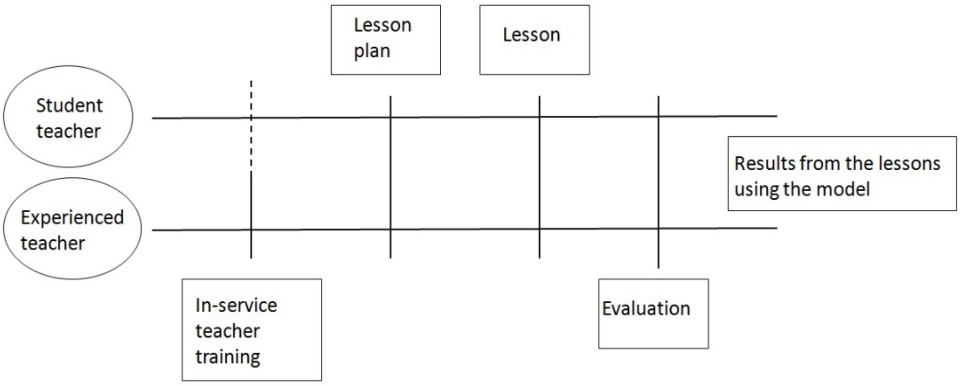


Figure 2.. Design of the study.

Firstly, the author gave a presentation at an in-service teacher training (see more in next section). 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 Appendix 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 video recorded and these videos came in need, since some of the results could not be understood by simply viewing the answers.

Preparations prior to teachers using the model

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 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 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 concrete and abstract concepts where presented under a social context of communicating between two tree huts. One of the noteworthy abstract 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 abstract 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 an abstract concept (vibration) lead to a problem of concrete materials (cans and threads), and this again lead to an investigation of another abstract 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 to 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 the school.

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.

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.

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.

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 quiet suburb area. Between the lessons, parents could easily come and pick up their kids to go home for lunch.

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 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 her 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’. Every now and then the supervising teacher gave different instructions 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 advice of the supervising teacher. When this happened, the student teacher decided that it was pointless to stop the work and the student teacher changed the plans accordingly.

Lesson outline

The lesson focused on teaching the different steps in 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 (see the list 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 a period of 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.

The use of the model

After all the lessons, the videos were analysed 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 abstract 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 more various topics you 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 STIXX 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 that the students used to make the actual design are round, hollow paper sticks made from old newspaper (Picture 3). 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)

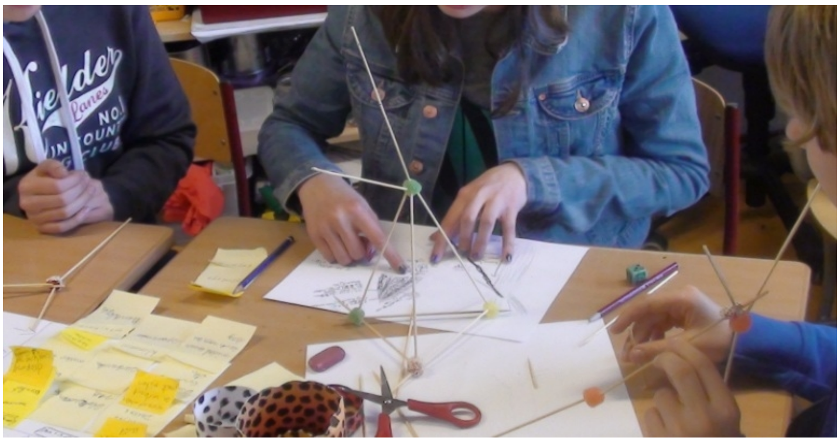
This extract shows that despite the fact that the topic of sustainability could not be included to the lessons she tried to teach even a bit of it to the students. Her plan was to address an abstract topic of consumer choices and the impact that everyone can have on the environment. Again, she would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

Picture 0. Students making the STIXXs.

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 practised 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).



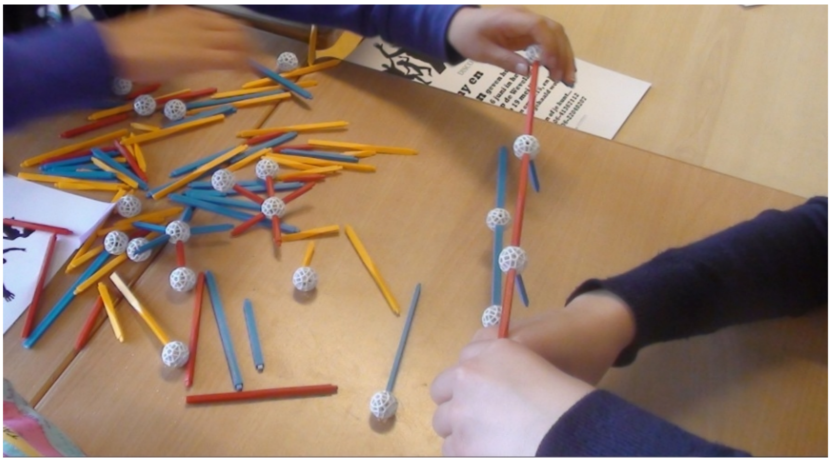
Picture 2. Students prototyping.

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 would have most likely 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 newspaper this takes longer but it still happens. Thus, what we are going to do is to spread fibre glass 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.



Picture 3. An early phase prototype.

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 of the groups. In order to play the game students needed to design baskets to collect 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 all the topics she wanted to to the process. She let the students to 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 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 abstracts 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 Pictures 2 and 3).

> 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.

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.

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.

Testing the model with the experienced teacher

The second teacher worked in a public elementary school in the Netherlands. She had 24 pupils in her class, age between eight and ten years. The class was a combination of children from two grade levels.

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. The pupils were used to work in teams and they had prior experience in designing.

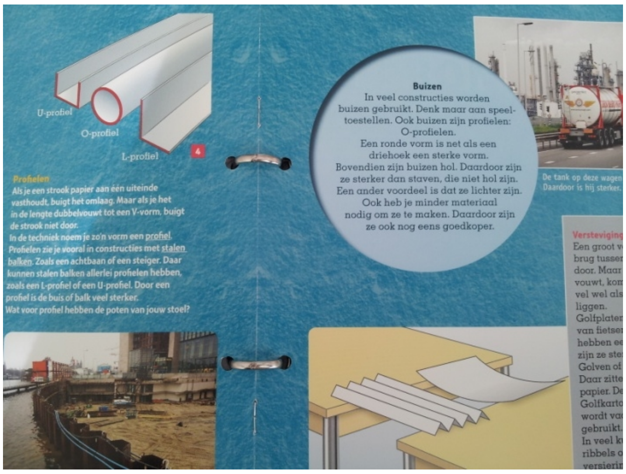
Often, during the lesson the teacher used a method where she put a stopwatch on, on the SMART Board for a specific amount of time (typically three to five minutes). The pupils were accustomed to checking how much time they still had to execute the task and they stopped what they are doing when they heard 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.

The topic of the lesson was constructions (see Picture 4) 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.



Picture 4. Theory from a text book.

The introductory part of the lesson is presented in Table 1. 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 at each point.

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. Discussion about the used terms.

Table 0. Teacher's lesson plan; Introduction.

After the discussion (First cell in Table 1), the teacher collected on the SMART Board the terms used to describe the steadiness of a bike (see Picture 5). 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 3. 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 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 one of the older pupils. From that point, 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…”*

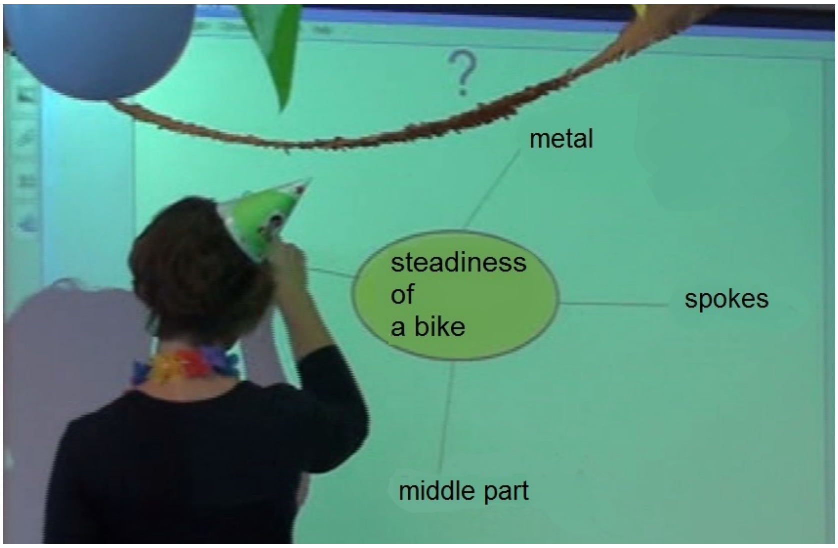
P5: “*Two triangles.”*

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 3). After finding an 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 applied 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 5. Teacher finalizing the mind map.

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 3, box 10. The answer of the last group was the ‘team box’ (see Picture 6, 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 3) presents how the movements between the domains actually happened during the introduction part. 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.

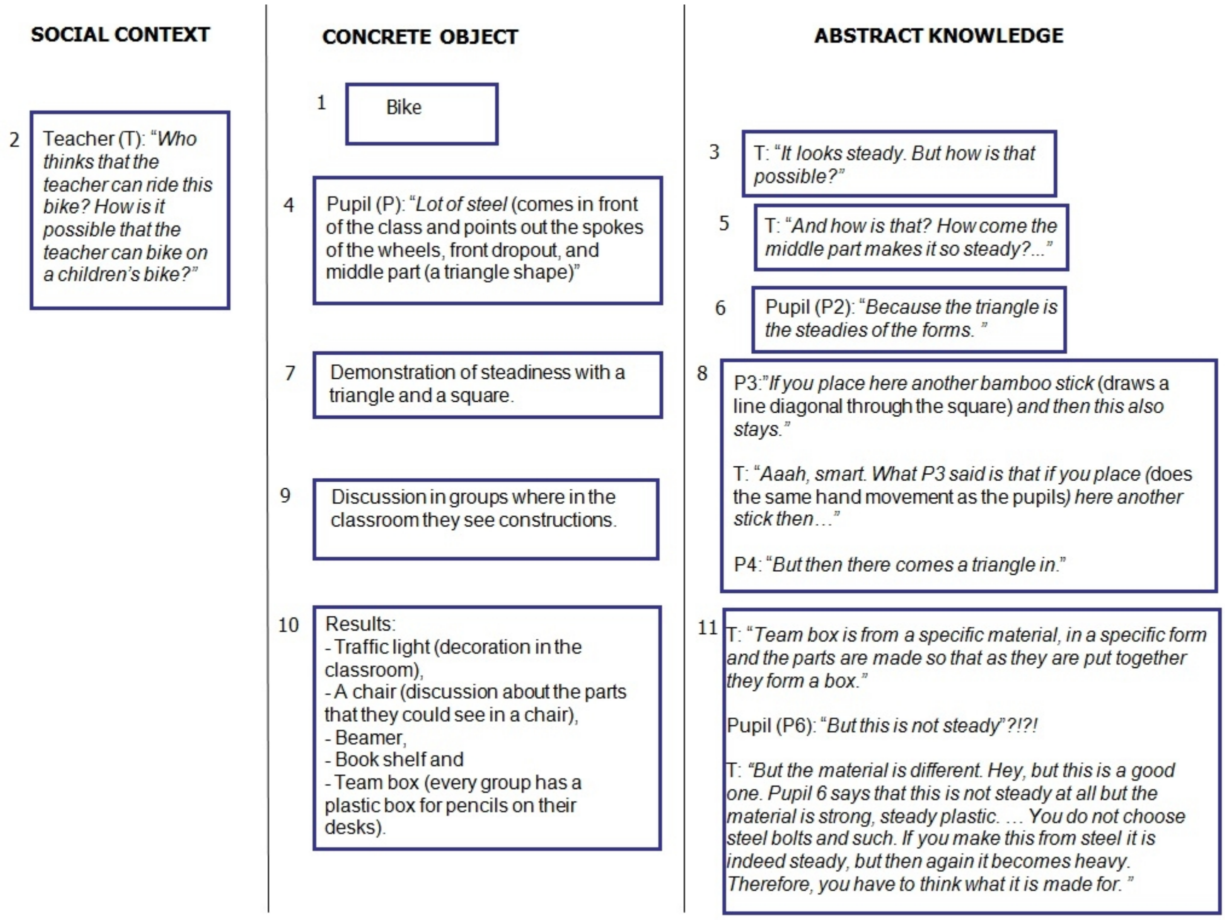


Figure 3. Movements between the domains.

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.

Picture 6. Pupils testing different profiles and the strength of them.

In the core part of the lesson (Table 2), the pupils experimented with different types of profiles. 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.

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.

Table 2. Teacher's lesson plan; Theory.

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 4, teacher's approach is shown. This figure provides 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.

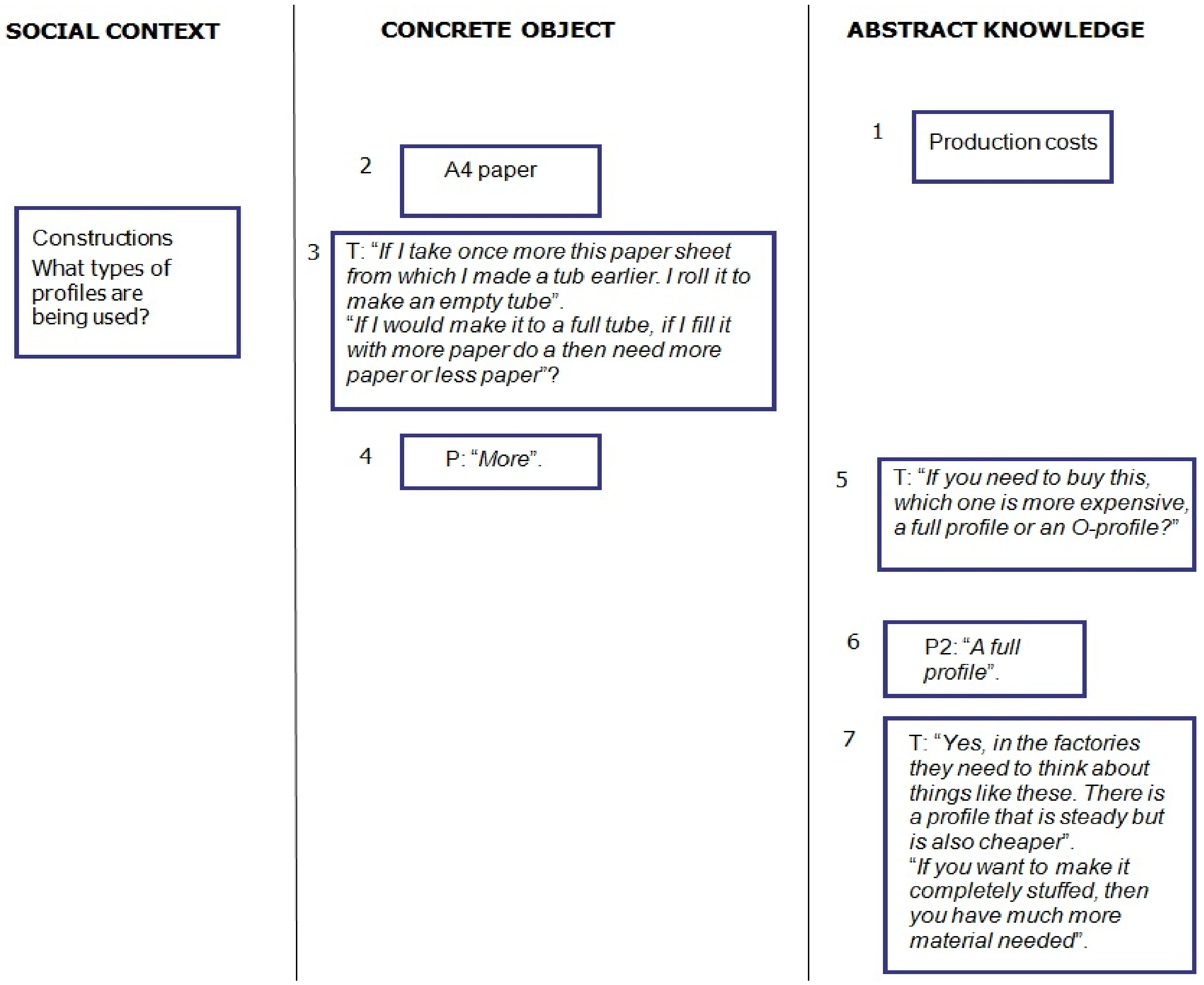
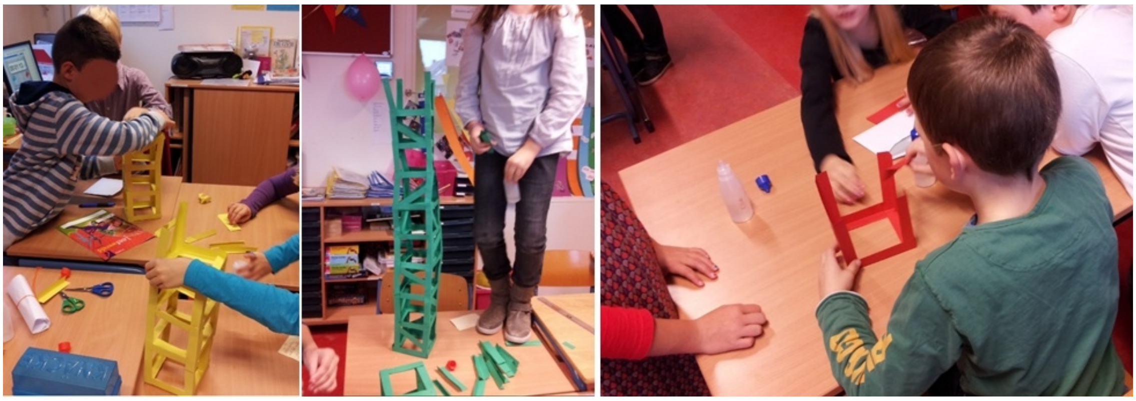


Figure 4. Teacher using the model to provide an answer to the question about production costs.

The biggest part of the lesson was dedicated to build towers from ready-cut pieces of paper (Picture 7). 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.



Picture 7. Pupils making construction.

Also a feedback part was included, during which each team gave feedback to two other groups (see Table 2, 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. 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.

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?

Table 3. Teacher's lesson plan; Discussion.

The table above (Table 3) 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 7, 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 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).

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 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. However, she pointed out that the movement between these domains was new to her. 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 several steps I had to take during the lesson, which was helpful."*

She stressed the fact that linking the domains and moving between them helped the pupils to understand the connections between concrete examples and abstract explanations. She was aware of the several steps she had to take during the lesson to accomplish this and she found this helpful for her teaching.

The teacher started planning the lesson by analysing 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."*

She used an object from pupils' everyday life; hence, the pupils were able to examine a concrete object, which helped them to think about what gives bicycle its steadiness. She incorporated several moments of collective reflection between the domains. The teacher also gives a small list of examples, such as social and concrete domains being connected when the pupils were looking for constructions in the classroom.

Another example of movements occurred when the pupils observed paper towers made by the others. In this case the movement was from abstract knowledge to concrete object.

The school practised 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 to give the lesson compared to what 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.* "

However, the model made her more aware of the necessity of several movements between the domains in order to gain better connection between theory and practice. She felt that this was helpful to her. When she thought that a connection was needed (again), she tried to accomplish this by 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 and she reported that the pupils responded to this new method as she expected.

Discussion

The literature study showed reasons why the approach of the model can be useful for teachers, and how the teachers can benefit from it in a sense of professional development. The model wants to help teachers to achieve a type of approach to science and technology education, where from planning the lesson to teaching it, teachers would bring together information about the topic (Koski, Klapwijk, & De Vries, 2011). When concepts are approached as such, the knowledge of them is built gradually and in a more investigative manner. The technique of the model is to apply 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 paper 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 the 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 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. 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 seems 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 3, 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.

Implications of the study

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 demonstrated. 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 with the students and combining knowledge. During the lesson(s), the progress and knowledge of the students were recognized by the teachers and they responded to it accordingly. And the concrete objects were indeed connected with the relevant abstract theories.

As far as the experienced teacher was concerned, only a short introduction of the model was needed for her to be able to teach the lesson. In her lesson the movements between the domains are clearly visible, both in her teaching and in the responses 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 planned and taught a lesson that satisfied her expectations. In her lessons the model was used to plan and to give her confidence in carrying out the lesson. The results are not self-explanatory but became evident during post-lesson discussions.

To plan a successful lesson with the help of the model, certain conditions need to be met. In both the cases mentioned, 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 topic in both cases was well planned, complete as well as complex enough with respect to the age of the students. On a larger scale, it is necessary to meet these conditions to prove that the model can be used as a teaching and learning aid.

Appendix

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?

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