Primary pupils' thoughts about systems. An exploratory study

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This paper presents a study into systems thinking among 27 primary school pupils, 8-to10-year-olds, and their teacher. The study includes, pre-test to the teacher and a group of pupils, lesson planning, the actual lesson and post-test to the pupils. The focus is on three concepts: do the pupils see a system as a structure consisting from main- and subparts, what are the inputs and output that they reason to be important for a system, and can they put boundaries to a system. Analysis revealed that the pupils showed some indications of machines consisting from parts with different functions, or that a sequence of steps is needed to complete a process. Systems, however, are mainly described in terms of what the user can experience, instead of what the machine itself does. The concept of input was more obvious to the pupils than the output. The impression of what a systems does, and what a user does, seemed to overlap, and this made setting the boundaries to a system more demanding. Nevertheless, by including basic principles of systems thinking, the teacher was able to introduce alternatives to approach the problems. Even though, the systems thinking was rather limited in larger sense, the pupils were able to reach beyond fair descriptions, and they used new practices to explain and label artefacts.

Introduction

Systems are an important concept in contemporary technology. Thinking in systems 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 (Von Bertalanffy, 1979; Barak & Williams, 2007). Furthermore, without knowledge of systems thinking individuals tend to describe situations with surface features (Booth Sweeney & Sterman, 2007).

For school's design classes systems thinking could offer a broader way to use knowledge. Development of technological systems offers pupils opportunities to understand, practice, influence and engage with technology (Svensson, Zetterqvist, & Ingerman, 2012). If we want to present an up-to-date image of what technology is, then the systems concept needs to be in it as well.

This paper introduces a qualitative study into systems thinking of primary school pupils. The focus is on the basic building blocks of systems thinking. It is examined whether bringing systems thinking into design class brings new ideas and ways to approach design and technology problems.

Study into systems thinking

Literature has few answers to what are the children's pre-concepts in systems thinking in the field of technology. Booth Sweeney and Sterman (2007) discovered that both students and teachers in middle schools have limited intuitive systems thinking abilities. One-way casual thinking is characteristic to them and explanations miss a reference to time (Booth Sweeney & Sterman, 2007). However, studies have also shown promising results in re-changing the thinking of students back to the systems type of thinking (Kali, Orion & Eylon, 2003; Assaraf and Orion, 2004).

For what is meant by systems thinking, literature has many definitions to offer, although 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 similar definition except they add one more 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 to think in systems way: thinking in models, interrelated thinking, dynamic thinking, and steering systems.

Lack of system dynamics skills is a result of teachers' inability to apply systems thinking in their teaching (Arndt, 2006). A key to improve skills in systems thinking is to expand these boundaries and increase the amount of factors and resources considered (Sterman, 2002). Systems thinking offers tools and processes to overcome our thinking boundaries and helps in expanding them (Sterman, 2002). Arndt (2006) also describes good learning environments, which integrate learning activities into larger concepts, and tasks to authentic, realistic contexts and refer them to matters relevant to students.

This study uses the definition of systems thinking by Booth Sweeney and Sterman (2002). However, the definition is too abstract to be used in primary school, and therefore, for the framework more practical approach is chosen. For the method of the study, teacher's knowledge level on systems was investigated to increase her confidence and abilities to use it in the classroom (Arndt, 2006). And hopefully, including systems thinking into the design class, the factors considered are increased, and more resources are evaluated (Sterman, 2002) during the design process.

Participants and method

This paper presents a study into systems thinking among 27 pupils (six of them, four girls and two boys, participated on the pre-test), 8-to10-year-olds, and their teacher. The study was conducted during winter months in 2011-2012 in a Dutch primary school as a part of a technology class. Both the pupils and the teacher have prior experience in designing.

The study was designed in a similar manner suggested by Tiberghien (1997), where data is 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 part the different aspects of teaching situation are analysed by focusing on the teaching session and the student progress during that session. (Tiberghien, 1997)

Hence, this study (Figure 1) started by designing and implementing a pre-test for the teacher to investigate the already existing thoughts and conceptions about systems before any introduction to the topic was given. This was tested by asking the teacher to explain three scenarios and one abstract definition about systems. Based on the given answers, a session to explain systems thinking took place. After this session the teachers was assisted to design a lesson for the classroom. The actual data was collected during a 70-minutes lesson, where pupils were encouraged to use all their senses to collect information about a washing machine and furthermore, to write down what goes in, what happens in between and what comes out in the end. Two weeks later, the pupils were given an assignment to draw and explain how a bread maker works, in a same manner as the washing machine earlier. Both pre-test and classroom activities were videotaped.

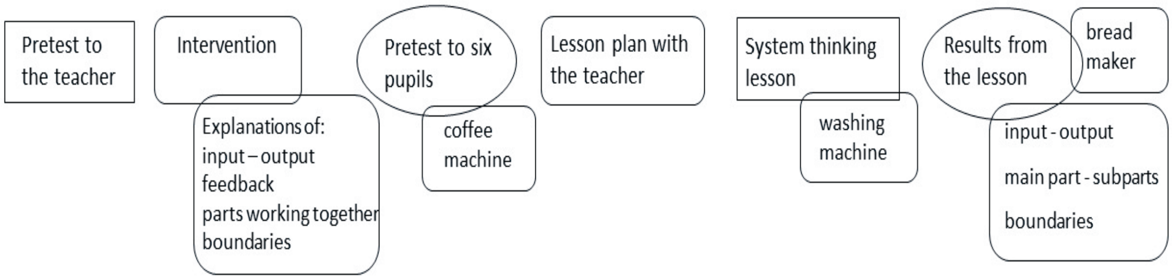


Figure 1. Design of the study

Research framework

Current perception of systems is moving towards 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). In 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 social aspect of systems is relevant this study concentrates on the engineering side of systems, and systems thinking supporting technological designs.

The framework (Figure 2) focuses on practical concepts and is, therefore, built on notions about systems themselves. De Vries (2005) defines a system as a set of parts working together. O'Connor and McDermott (1997), as well as Booth Sweeney (2011), compare a system and a heap, and one of the crucial differences they draw attention to is how in a system parts are connected and they work together, unlike in a heap they do not. Together with the definition by De Vries and this dichotomy, a notion of a main part and subparts, and these parts working together is formed (this also appears in the concepts of systems thinking). The idea is to see whether pupils have a tendency towards black-box type of thinking about machines or do they recognize a connected structure inside of a cover of a machine.

The second notion is systems having an input and an output. Here, De Vries (2005) refers to German literature, in which inputs and outputs are defined as a set of three components: matter, energy and information. This categorization is used to investigate do the pupils have an idea about inputs and outputs, and what they consider 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 is used to reveal information to what extent the pupils understand what is meant by a system. Knowledge of the system boundaries is used to indicate the understanding of the complexity of a system.

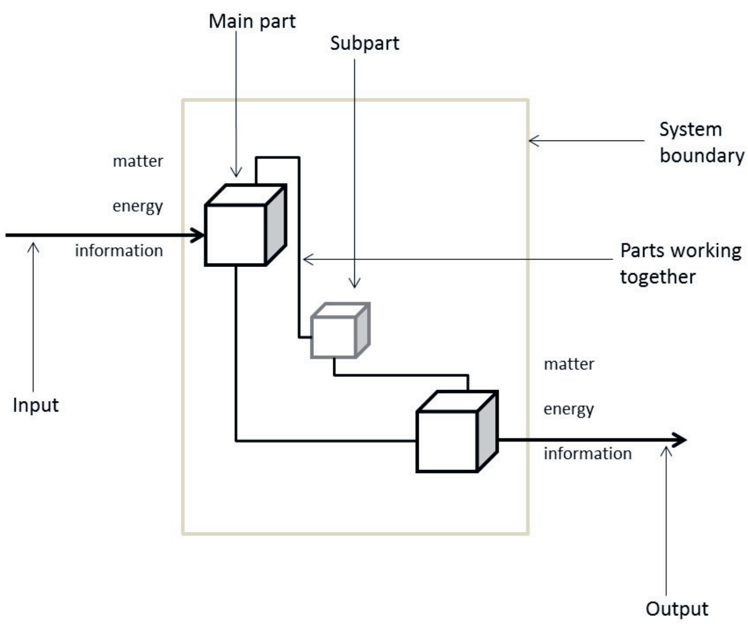


Figure 2. Research framework and its components

Analysis

Here, the results of the pre-test, lesson, and post-test are presented. The pre-test questions, for both the teacher and later on to her pupils, were concerned about how a coffee machine works. In the lesson, the pupils investigated elements of a washing machine, and a process of doing a wash. The post-test was about implementing the ideas evoked during the lesson to another machine, namely a bread maker.

In this analysis, the answers of the pupils are at the centre of the scope, and the teacher is used as an explaining factor. E.g., in the feedback session, after the pre-test of the teacher, most of her questions were about input and output. This influenced on how the teacher started to view systems, and also how she asked and directed the questions during the lesson. This is taken into account when viewing the answers.

Pre-test

The pre-test sessions started with pupils making cups of coffee in the teachers' room (Picture 1).

Picture 1. Left: pupils making coffee. Right: answering to the questions about the same machine

Figure 3 presents a part of a discussion about what is needed, and what does the machine do in order to make a cup of coffee.

....
Teacher (T): What more is needed?
Boy (B): Hot water, I think.
T: Did you see it 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 is some preparations...
T: What are these preparations?
B: Hmmm, that the beans are grinded.
...
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 cord and then the water stays there warm and then it comes out warm.

Figure 3. Discussion between the teacher and two pupils, a boy and a girl

In this extract, an input (matter: water) and an output (energy: warmth) can be observed. The boy realised the need for water by himself, however, the output was introduced by the teacher. Similar to Arndt (2006) the pre-test showed that one type of input is acknowledged, and this satisfied the pupils. Here, the teacher knew about the other types of inputs and outputs, and therefore, she tried to trigger the pupils to think about them as well.

Furthermore, the reason why coffee is/stays warm was approached inverse by the girl. She was not concerned about how the machine makes warm coffee, but how to keep its temperature. However, what this conversation prompted was that the boy started to think about the steps, which the coffee machine needs to go thought. He said that the coffee machine resamples a thermos can, and that keeps the water warm. Hence, in the machine, there is a part that controlling the temperature of water.

Additionally, all the pupils included grinding the coffee beans into the process. In here, 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 sample (Figure 4), the two girls considered more inputs needed for the coffee machine to function. They listed all three types of inputs: warm water (matter), electricity (energy) and pressing the button (information). The only output mentioned is the coffee coming out. These girls, like the pair in the previous sample, recognized that something needs to come from outside of the machine in order for it to function.

...
T: What do you need to make coffee?
G1: Warm water, flow through the coffee powder...
T: What do you mean with the flow?
G2: For the plug (electricity) .
T: And for what is the electricity needed?
G2: To warm up the water.
G1: For it to function, if you press the button, something is going to happen.
....
T: What steps will the machine do?
G2: Make it warm, then it 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.*

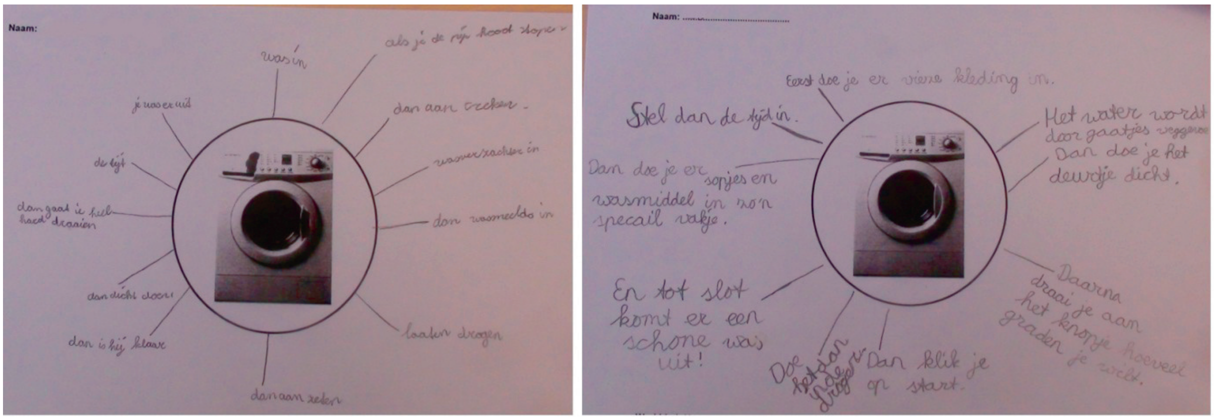
Figure 4. Discussion between the teacher and two girls

In the second part the girls are invited to think about the process as sequence of steps. They describe a linear process, with no feedbacks. Nevertheless, different phases and parts doing something together appears in the description.

During the lesson

In the beginning of the lesson, pupils received a closed envelop, which they could not open. They could only smell through the holes what was in it. The pupils were asked to write down what they smelled, and for what it is used for (envelop contained washing powder). After this, the pupils were invited to talk in groups of four about what they had smelled, and to write down a group answer. After these 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 topic regarding doing laundry, such as "*What does a centrifuge do?*" Afterwards, the whole class participated on 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 in to a washing machine, what does the machine do, and what comes out (what happens in the end).

The answers were mostly about what goes in. Generally, the lists included fabric softener, detergent, clothes, water (matter). However, also electricity (energy), time and pressing buttons (information) were mentioned (Picture 2).



Picture 2. Example answers about washing machine

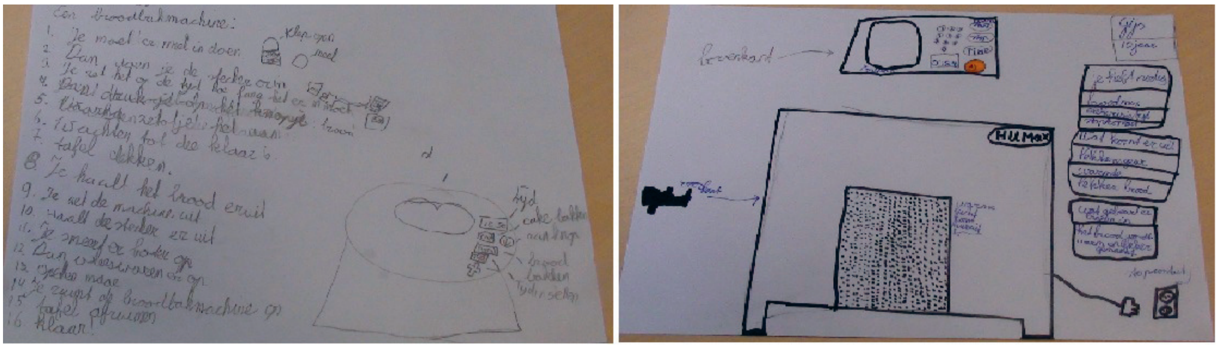
To the question what does the machine do, the pupils did not describe the different phases a washing machine undergoes, but they commonly observed it from their point of view: "*It turns around very hard*", "*Wait*", "*You feel shaking*", "*It turns hard so that the water goes out from the clothes*", "*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 needed to imagine what they can sense when a washing machine is on.

Answers also included straight forward 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*". These answers are again from the user's point of view but an interesting addition on 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.

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

Post-test

In the post-test, the pupils drew and wrote, in a same manner as with the washing machine, how a bread maker works (Picture 3). The answers covered different types of inputs and outputs. Naturally, bread mix or flour were the most popular ones, however, electricity, outlet and buttons were also common replies. Surprisingly many of the pupils replied that a bread maker will not function unless an outlet is plugged in. It could be that a coffee machine is more of a standard kitchen appliance, and therefore, does not need to be plugged in every time used. Unlike a bread maker that is more likely to be stored in a cupboard. Furthermore, because the pupils were invited to draw their bread makers, this may have caused them to sketch buttons as well, and this way they were also part of the inputs.



Picture 3. Example answers about bread maker

For the outputs almost all the pupils mentioned all three types: bread (matter), smell (information) and steam (energy). Also warmth and some sort of sound indication when bread was ready were included. The earlier assignment to use all senses likely helped to include such outputs.

To the question what happens inside the machine, pupils replied about the bread being made inside or that the machine mixes the flour. However, there was no clear indication of specific parts working together. As machines, coffee machine is visibly clearer structured than a washing machine or a bread maker. The pupils could have observed different sub functions that a coffee machine goes through, but in a case of the other two, everything happens behind/under a closed lid. What happens inside of a machine was a challenging question for the teacher as well, and therefore, this aspect of the study did not get the attention it required. Furthermore, few pupils mentioned the whole procedure from pouring the flour into the machine, all the way to eating the bread and cleaning the table. It seems that separating the tasks between a machine and a user is still problematic to some hence, the system boundaries are unclear.

Conclusion

The pre-test and the lesson showed that the concept of input is more obvious to the pupils than the output. After encouragement, the pupils came up with more outputs but often the obvious function of the machine (what it does or produces) was considered, and no further thinking was thought to be necessary. However, in the post-test the inputs were still mostly viewed in a same manner as before; generally they were about the matter but also energy and information were mentioned. The change had happened in the outputs, where all three categories were now included. The pupils were not able to explain relations connecting inputs, processes and outputs, like students Ginns, Norton and McRobbie (2005). But on the other hand, the way post-test asked pupils to draw and write on the drawing, does not 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. No clear image of whether the pupils saw machines as something with a main part and subparts working together can be formed. Some indications of a part functioning inside another or sequence of steps can be observed in the pre-test. For this to happen a push from the teacher was needed. Machines were mainly described in terms of what the user can experience, instead of what the machine itself does. The comprehension of what a systems and a user does, seemed to overlap, and this made setting the boundaries to a system more demanding.

A lesson requires a firm idea of a system to be worked with (Boersma, Waarlo & Klaassen, 2011). The difference in how the example machines can be observed influences on how well the pupils can describe its functions. The difficulties in seeing system boundaries and different parts working together force the assignment to be concrete and the topic preferably something already known. Instead of the bread maker –assignment, the pupils were given a task to design a system that helps them (with homework, walking the dog etc.). Eventually, the pupils were not able to think in a way intended, their focus was on what the machine could be about, and what would be a funniest one.

This study is a small sample, but the results show that system thinking can be included to the design class and the thinking boundaries (Sterman, 2002) can be, if not overcome, expanded with a relatively straight forward 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.

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