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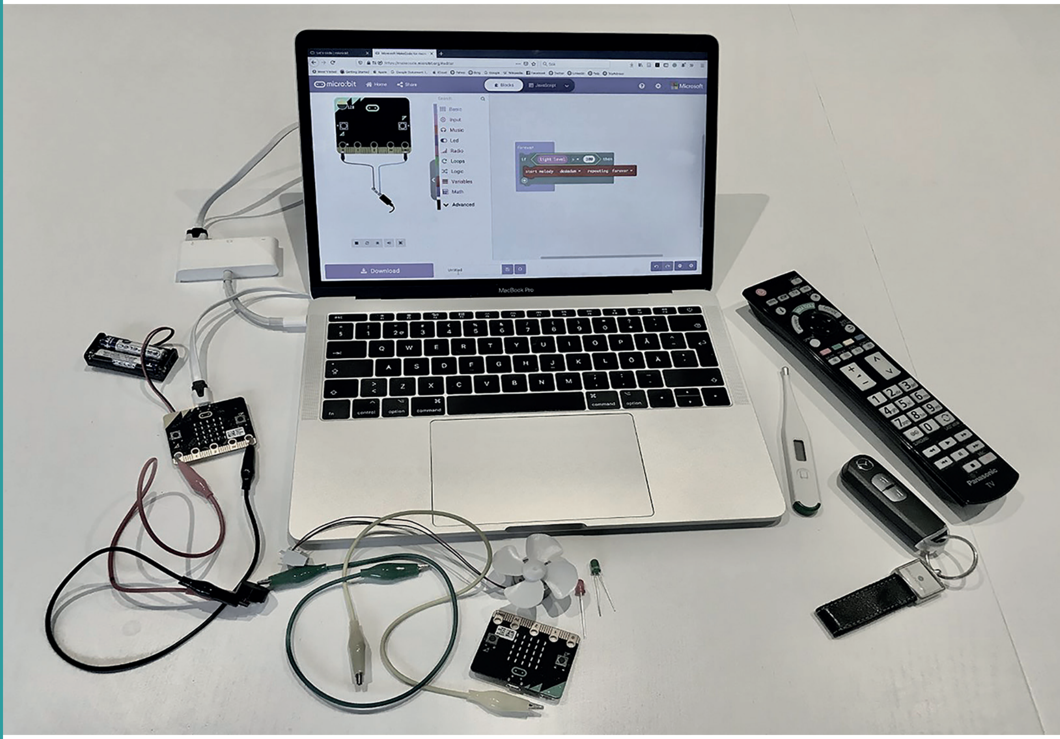

Seeing the parts, understanding the whole

A technology education perspective on teaching and learning in processes of analysing and designing programmed technological solutions

Anne-Marie Cederqvist

UNIVERSITY OF GOTHENBURG

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Abstract

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Analysing and designing Programmed Technological Solutions (PTS) has been introduced as a part of technology education in an effort to bring elements of programming into the curriculum for compulsory school, in order to develop pupils' understanding of how PTS work and are controlled by programming. However, what an appropriate understanding entails at this level remains to be articulated, particularly how this understanding looks from a pupil's perspective. Such descriptions are paramount for allowing teachers to make pedagogical decisions on what specifically is to be addressed in the classroom. The challenges are increased by a dependency on programming materials, which give a structure to teaching and learning that is not necessarily in line with pedagogical needs. Therefore, the aim of this thesis is to identify key elements that are important to address in teaching and learning technology in the processes of analysing and designing PTS. The knowledge domain of PTS, in relation to technological literacy, frames the results from three phenomenographic studies that investigate the ways pupils (aged 10-14) experience PTS when analysing and designing PTS in the contexts of the BBC micro:bit material and PTS from everyday life. The results show that understanding programming concepts and how to produce code are key elements, and most importantly, that there are other key elements embedded in the processes that it is necessary to direct attention to. These are: knowledge related to the dual nature of PTS; knowledge related to the programming material used in the processes; the relevance structures provided by the contexts in terms of experienced part-whole structure of PTS; and the use of systems thinking to discern the part-

whole structure of PTS. Together these direct attention to the structural and functional nature of PTS, which must be understood in order to understand how PTS can be controlled by programming. Thus, these key elements are important to consider in pedagogical practice in order to promote learning with regard to PTS.

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Kippholmen, 6th June, 2021

Chapter 1: Introduction

Education for understanding digital technology

Digital technology surrounds us in daily life and we have become more and more dependent on technological solutions that are controlled by programming. However, for most people, these technological solutions are something that they just use, without reflecting on the underlying technology (Compton & Compton, 2013; Svenningsson, 2019). Because of this, most of us may be considered as uncritical consumers of technology. Dakers and De Vries (2019) describe this as the "black box syndrome", i.e. consumers of technology are only interested in the input and output, and what happens in between is not of relevance. On the one hand, this way of perceiving technology might facilitate the use of technological solutions, and an awareness of their functions. On the other hand it is alarming: if we only understand technology as objects that we use, without understanding the processes or knowledge hidden behind them, it will be difficult to critically analyse and evaluate them. Therefore, technology education has an important purpose to fulfil. By developing pupils' understanding of how technology works, i.e. its structure and function, the "black box syndrome" may be prevented.

The increased use of digital technology and the need for understanding digital technology have led to changes in curricula all over the world. In 2018, changes were made to the Swedish general curriculum and the syllabi for the individual subjects, in order to clarify and emphasise the importance of developing pupils' digital competence, i.e. competence necessary to be able to learn and work in the digital society (Ilomäki et al., 2016). The importance of understanding how digital technology works was highlighted, and programming was introduced as a significant element of digital competence. Unlike several other countries that have implemented programming in curricula, Sweden did not choose to introduce programming as a separate subject, but let it become part of existing subjects such as technology and mathematics. In this way, pupils are expected to obtain different perspectives on programming, and thus, broader knowledge, which forms the basis for more complex knowledge of programming higher up in the education system (Skolverket, 2017).

For technology teachers as well as other teachers, both in Sweden and in other countries, the implementation of programming in curricula and syllabi has meant a striking challenge. Many teachers feel they have little experience of how to organise teaching regarding programming, as well as feeling uncertain of what pupils are expected to learn, and how to address pupils' difficulties (Lärarnas Riksförbund, 2017; Sentance & Csizmadia, 2017; Webb et al., 2017; Vinnervik, 2020). Furthermore, there is a scarcity of didactic research that can guide teachers in what to address in relation to subject-specific content (Passey, 2017; Rolandsson, 2015). Therefore, the implementation of programming as educational content has, to a large extent, come to be based on knowledge and concepts derived mainly from computer science. This is mirrored in teaching and the expected learning outcomes of different programming activities, which are often described as related to computational thinking and generic skills, such as cognitive skills, collaborative skills and problem-solving skills (Nouri et al., 2020). However, in Sweden, as mentioned above, programming has been implemented as part of existing school subjects. One of these subjects is technology, which has its own specific purposes and expected learning outcomes. Further, as De Vries (2011) argues, when implementing new content in the technology syllabus, it is important to not lose sight of the purpose of technology education. That is, programming needs to be discussed in relation to what technology education is, as well as adapted to what technology education is expected to deliver in terms of learning.

Programming as part of technology education

One of the overall purposes within technology education is to develop pupils' understanding of technological solutions that surround us in everyday life. Hence, teaching is expected to develop pupils' knowledge of technological concepts and processes, in order for them to gain tools to identify and analyse technological solutions, based on their appropriateness and function (Skolverket, 2018). The implementation of programming in technology education is expected to develop pupils' understanding of how digital technology works. This implies developing pupils' knowledge in regard to their ability to identify and analyse appropriateness and function of technological solutions that are controlled by programming, which I refer to in this thesis as programmed technological solutions (PTS), but also in regard to their ability to design PTS and to control them with programming (Skolverket, 2017).

Therefore, when considering knowledge in relation to the processes of analysing and designing PTS, there are limitations in only looking at pupils' learning in terms of computational thinking and other generic skills, without directing attention to the technological content and the technological knowledge involved.

A common way to contextualise educational content with respect to PTS is to let pupils take part in practical activities where they use different programming materials such as the BBC micro:bit, Lego Mindstorms and Arduino. An evaluation of technology education in Swedish compulsory school carried out in 2014 by the Swedish Schools Inspectorate [Skolinspektionen] shows that practical activities are common when teaching technology. However, the report also shows that the teachers seldom explicitly make a connection between the practical activities and the theoretical knowledge that underpins them (Skolinspektionen, 2014). Moreover, the report describes an unreflecting use of pre-made teaching materials, which may result in the practical activities not directing attention to the aims and learning goals of the syllabus for technology. As a result, pupils risk not perceiving the characteristics of technology, and not developing subject-specific knowledge. Another important aspect to consider is the amount of time allocated for technology education in the Swedish compulsory school. Today, 200 hours are allocated to teach technology from Grades 1 to 9. This means about 20 hours a year, for each grade. The time limit raises issues concerning how to organise pertinent and meaningful technology teaching where pupils learn technological knowledge aligned with the technology syllabus. There is a need to reflect on what pupils are expected to learn and how they learn this, with respect to what technology education is expected to deliver in terms of learning. Hence, the implementation of programming and PTS as part of technology education in Sweden, as well as in a broader international context, needs to be seen in the light of issues such as: what characterises technology, and what technological knowledge are pupils expected to learn with respect to the technology syllabus, and how do they learn this in processes of analysing and designing PTS. Therefore, to be able to discuss these issues, attention should be directed towards the knowledge domain of PTS.

In technology education, the term technological literacy is used for defining the knowledge base, and thus what pupils are expected to learn (Hallström, 2011). Technological literacy refers to general technological knowledge that every citizen needs for understanding and managing technology in their everyday life (ITEA, 2007). This definition of technological literacy takes its origin from philosophy of technology and its broader epistemological stances for defining technology and technological knowledge. Thus, philosophy of technology is a useful resource for providing insight into what characterises technological knowledge and how it differs from other kind of knowledge. This insight is of importance when determining what knowledge is expected to be taught and learnt in technology education (De Vries, 2005). Although programming has already been implemented as part of technology education in compulsory school, little research has paid attention to programming in relation to the teaching and learning of technological knowledge. To address this gap, this thesis draws on assumptions from philosophy of technology regarding what technology is, and what characterises technological knowledge, in order to discuss teaching and learning technology specifically with respect to PTS. Therefore, in accordance with a technology education perspective, the subject-specific content will be examined in relation to the pupils that are expected to learn it.

A technology education perspective

Didactical research is characterised by studies that direct attention to meaning and purpose of teaching and learning, where relationships within classroom contexts are empirically analysed in relation to curriculum requirements in terms of subject-content and competencies (Ligozat & Almqvist, 2018). From a technology education perspective, this implies investigating the meaning and purpose of teaching and learning technology. Attention is directed to the relationships between the pupils and the technological content; between the teacher and the pupils; and between the teacher and the technological content, which are taken into account when analysing opportunities for technological content to be taught and learnt (Bronäs, 2016). The didactical triangle is commonly used to illustrate these relationships (Hopmann, 2007). Rezat and Sträßer (2012) suggest that in some teaching situations, tools and artifacts such as a teaching material also play an important role. Thus, this needs to be considered as a factor which should be taken into account in learning situations, and hence the didactical triangle expands to a tetrahedron (see Figure 1).

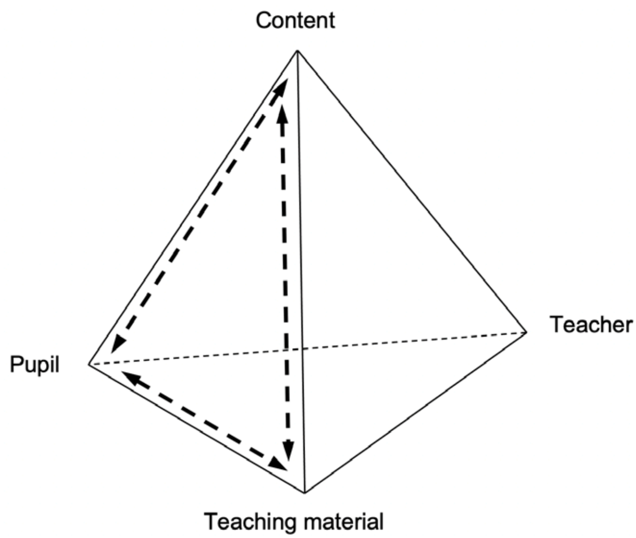

Figure 1 The didactical tetrahedron representing the relationships between the teacher, the pupil, the content and the teaching material

(Developed from Rezat & Sträßer, 2012, p. 645).

The tetrahedron visualises the complexity of the relationships between the factors involved in teaching and learning situations. Initially the content is identified on the basis of the subject's knowledge domain and on what knowledge is important for pupils to learn. The identified content is then transformed by the teacher into teachable content based on requirements in the syllabus, by taking into account pupils' relationship to the content (Bronäs, 2016). Thus, the teacher needs to be aware of what the content should be, and also aware of the relationship between the pupils and the specific content, i.e. how pupils experience the content. Furthermore, if teaching material is involved, teachers need to be aware of how pupils experience the teaching material, as well as the material's ability to direct attention to important aspects of the content.

Thus, the aforementioned relationships are important to investigate, both for understanding the relations between teaching, learning and content, and for shaping education (Ligozat & Almqvist, 2018). Therefore, this thesis directs attention to the meaning and purpose of teaching and learning technology regarding the subject-specific content of PTS in technology education. From a technology education perspective, the thesis takes its point of departure in the knowledge domain of PTS in order to identify what technological knowledge is of importance for pupils to learn. What lies at the heart of the thesis is the relationships between the pupils, the content and the teaching material (see the arrows in Figure 1). Thus, the ways pupils understand and experience PTS in processes such as analysing and designing PTS is important to investigate. To this end, the phenomenographic perspective of learning is used to empirically investigate these relationships, with the aim of identifying what is critical for pupils to discern in order to be able to learn technology with respect to PTS in these processes. In this way, the knowledge domain of PTS sets the framework for what elements are important to address, and the empirical studies provide a perspective based on pupils' experiences regarding what elements are important to address in teaching and learning situations in order for pupils to learn. By aligning the knowledge domain of PTS with the perspective of the pupils, the results of the thesis are expected to contribute knowledge to technology education regarding what key elements are important to address in teaching and learning situations, in order for pupils to learn technology with respect to PTS in the processes of analysing and designing.

Aim and research questions

The overall aim of this thesis, from a technology education perspective, and on an empirical basis, is to identify key elements of teaching and learning technology with respect to programmed technological solutions (PTS). To achieve this aim, the thesis aligns theory and practice by taking its point of departure in the knowledge domain of PTS and bringing this together with the empirical base constituted by investigations of pupils' relationship to PTS. The thesis attempts to answer the following overall research question:

- What key elements are important to address in teaching and learning technology in the processes of analysing and designing programmed technological solutions (PTS)?

The empirical work has been conducted in the context of the Swedish compulsory school, with pupils aged 10-14, framed by the national technology syllabus. The programming material BBC micro:bit was used as a context to represent PTS. In an effort to find answers to the overall research question, pupils' ways of understanding and experiencing PTS were empirically investigated within the framework of the three papers included in this thesis, which address the following three research questions:

- What are pupils' different ways of understanding PTS when analysing their structure and function? (Paper 1)
- What technological knowledge do pupils need, in terms of critical aspects, when designing and coding a PTS with BBC micro:bit? (Paper 2)
- In what way do pupils sequentially experience central phenomena in the process of designing PTS with the BBC micro:bit, and what effect does the way of experiencing have on how the process unfolds? (Paper 3)

Descriptions of concepts and terms

The concept digital technology is used in the thesis as an overall concept to describe the technology we use in everyday life, such as systems, tools and devices that are based on digital information in terms of a program to achieve certain functions.

The concept programmed technological solutions (PTS), used in this thesis, represents what is described in the Swedish syllabus for technology as technological solutions that are controlled by programming. These may be physical and tangible technological solutions, as well as non-physical and intangible technological solutions. However, in line with the research interest of this thesis, which is framed by the national technology syllabus and the use of physical programming materials, PTS mainly refers here to physical and tangible technological solutions that pupils are expected to be able to identify and analyse, as well as to be able to design and control with programming (Skolverket, 2017). The term programming materials in this case refers to instructional materials used in teaching to provide opportunities for pupils to learn technological concepts and processes.

Outline of the thesis

The next chapter presents the knowledge domain of PTS in terms of technological literacy and its origin in philosophy of technology. The aim is to place the thesis in a context, and to describe what technology is and what characterises technological knowledge with respect to PTS. The chapter also presents findings from previous research in relation to programming as a constituent of understanding PTS, and in relation to pupils' perceptions of PTS.

The third chapter presents phenomenography as the perspective on learning taken in this thesis. The premises and theoretical assumptions that underpin phenomenography are described, and put in relation to the research interest of the thesis.

In the fourth chapter, the research design is presented. The phenomenographic research process, including the collection of the empirical material and the analysis, is described and discussed in relation to trustworthiness, credibility, transferability and ethical considerations.

The fifth chapter reports the synthesised results from the three papers in relation to the knowledge domain of PTS. The results are then presented as key elements important to address in teaching and learning technology in the processes of analysing and designing PTS.

In Chapter 6, the results of the thesis are discussed in relation to the new insights the results contribute, and what implications the results have for theory and practice, as well as limitations and strengths of the results, and suggestions for future research.

The seventh chapter presents the conclusions draw from the thesis, and in Chapter 8, a Swedish summary of the thesis is provided.

The included papers

Paper 1

Cederqvist, A. (2020). Pupils' ways of understanding programmed technological solutions when analysing structure and function. *Education And Information Technologies, 25*(2), 1039-1065. https://doi.org/10.1007/s10639-019-10006-4

Paper 2

Cederqvist, A. (2020). An exploratory study of technological knowledge when pupils are designing a programmed technological solution using BBC Micro:bit. *International Journal of Technology and Design Education.* https://doi.org/10.1007/s10798-020-09618-6

Paper 3

Cederqvist, A. Designing and coding with BBC micro:bit to solve a real-world task – a challenging movement between contexts [submitted 2020, in review]

Chapter 2: The knowledge domain of PTS

Technological knowledge is to a great extent context-bound. In this sense, technology differs from, for example, science and mathematics, which work with abstractions and idealisations to develop universal knowledge about reality, while technology works with concrete reality and its complexity (De Vries, 2005, p. 38). De Vries describes technological knowledge as related to specific situations, and therefore not always applicable as general knowledge to other situations. Thus, a main difference between technological knowledge and scientific or mathematical knowledge relates to their respective dependence on or independence of context. The abstract knowledge in science and mathematics is universal, regardless of contextual conditions. Technological knowledge, on the other hand, develops in a specific context and is dependent on contextual factors. For example, technological problem-solving is highly context-bound and requires extensive knowledge of concepts, procedures and tools in the specific context where the problem is to be solved (McCormick, 2004). Accordingly, when considering knowledge in relation to the technological activities that are of interest in this thesis, i.e. analysing and designing programmed technological solutions (PTS), there are limitations in focusing on learning only in terms of generic skills, without directing attention to the technological content and the technological knowledge involved. Therefore, in order to examine what characterises technological knowledge with respect to PTS, this chapter directs attention to the knowledge domain of PTS, from the perspective of technological literacy, which has its origins in philosophy of technology. In the chapter that follows, phenomenography is introduced as the theory of learning that underpins the empirical studies in this thesis. Attention is specifically directed to the capability of discerning the part-whole structure of a phenomenon, and how this is affected by contextual factors.

PTS and programming as part of the curriculum

The digital transformation of our society has had a huge impact on the labour market, education and our social lives, and digital technology has become a central part of our everyday lives. Almost everything we take part in at work, in education, and in social life requires digital competence, i.e. the skills and knowledge necessary for being able to learn and work in the digital society (Ilomäki et al. 2016). This has led to the implementation of digital competence as part of curricula in many countries, in order to prepare pupils to take part in the digital society. In the Swedish curriculum for compulsory school, digital competence is described on the basis of four aspects (Skolverket, 2017): understanding the impact of digitalisation on society, being able to use and understand digital tools and media, having a critical and responsible approach, and being able to solve problems and put ideas into action. In the Swedish curriculum, programming is part of all aspects of the digital competence pupils are expected to develop. According to the Swedish National Agency for Education [Skolverket], this implies that pupils are expected to develop a broad perspective on programming, which goes beyond learning to write code, and involves an understanding of its effects on society, including a democratic dimension, as well as controlling and regulating technology, problem-solving, and creativity. This broader perspective on programming is expected to form the basis for further knowledge development regarding programming higher up in the education system.

In the discussion concerning digital competence and programming in compulsory school, computational thinking has been highlighted as an overall concept that can be practised when programming is introduced as an element in teaching (Mannila, 2017). Wing (2006) describes computational thinking as a fundamental ability that all people need to develop in order to be able to use computers to solve problems. According to Wing, computational thinking may also be seen as a tool for thinking in most areas in modern society in order to formulate and solve problems. In the commentary material accompanying the revised Swedish curriculum (Skolverket, 2017), computational thinking is mentioned as a computer science concept that may be linked to knowledge in several parts of the general curriculum and the syllabi for individual subjects, since it relates to problem-solving, logical thinking, seeing patterns and creating algorithms. The discussion regarding programming and computational thinking also involves transfer effects, i.e. whether skills related to computational thinking can be transferred to several school subjects. Wing (2006) argues that working with programming tasks will develop computational thinking, which is a constituent of a generic problem-solving ability that may spill over to other school subjects. However, there is a difficulty with seeing problem-solving as a generic ability, not taking into account the specific knowledge related to the context, the activity and the problem to be solved (Billet, 2003; Hennessy et al., 1993). Moreover, the concept computational thinking lacks a common definition and has been criticised for being blurry and abstract with respect to what it represents in terms of thinking, and how it may differ from other ways of thinking (Grover & Pea, 2013; Vinnervik, 2020). Despite the above-mentioned shortcomings regarding the definition of computational thinking and seeing problem-solving as a generic ability, a study by Nouri et al. (2020) shows that Swedish teachers expect that pupils develop computational thinking, and other generic abilities such as cognitive skills, language skills, collaborative skills and problem-solving skills when taking part in programming activities. These generic abilities are of importance in relation to the overall goals set out in the Swedish curriculum in compulsory school in terms of the knowledge that pupils should have acquired by the time they leave compulsory school (see Skolverket, 2018). However, we have to bear in mind that programming has been implemented as part of existing subjects with their established subject-specific content and learning goals. Hence, teaching activities involving programming have to be aligned with what is said in the curriculum (Vinnervik, 2020), i.e. in the syllabuses for the subjects that include programming. With regard to the research interest of this thesis, the focus is on the goals of the syllabus for technology, which involve developing pupils' ability to identify and analyse the structure and function of existing PTS, but also developing their ability to design new ones and control them with programming (Skolverket, 2017). However, there is still a need for more research regarding the subject-specific content of PTS in technology education and what this implies for teaching and learning technology. Therefore, to achieve the overall aim of this thesis, i.e. to identify key elements of teaching and learning technology in processes of analysing and designing PTS, the point of departure is taken in the knowledge domain of PTS.

The epistemological roots of technology education

Within academia, there is no specific technology subject corresponding to the technology subject in compulsory school, as there is with mathematics and science. Hence, there is also a lack of specific knowledge structures to be transformed by teachers into teachable content based on the requirements of the technology syllabus. Therefore, educational research has devoted a great deal of space to defining what technological knowledge is, as well as defining the primary goals of teaching technology. To this end, technological literacy has been used for defining the knowledge base for technology education (Hallström, 2011). Technological literacy refers to the technological knowledge that every citizen needs to be able to understand, manage, use and evaluate technology in everyday life (ITEA, 2007). It can be knowledge related to individual technological objects such as a flashlight, or knowledge about larger technological systems such as water supply systems, but today it is also to great extent knowledge for understanding, using, managing and evaluating digital technology in everyday life.

During the last few decades, our use of digital technology in everyday life has increased. On the other hand, our understanding of the technology itself has decreased due to its increased opacity (Stiegler, 1998). This may be referred to what Dakers and De Vries (2019) describe as the "black box syndrome", i.e. consumers of technology are only interested in the input and output, and what happens in between is not of relevance. Stiegler (1998) suggests that this opacity is a result of the difficulty in explaining the knowledge involved, due to this knowledge being broken down into separate domains. In relation to the overall goals of technology education, to develop pupils' understanding of technology in everyday life including PTS, this implies that the knowledge that is spread over separate domains need to be identified and made discernible in order to bring clarity to the opaque. To this end, this thesis starts out by seeking guidance from philosophy of technology, where Mitcham's framework for defining what technology is provides the basis for further investigation of key elements, taking into account previous research from the technology education field as well as from the computer science field.

What is technology?

If we ask people what they consider technology to be, we may end up with a variety of answers. Most of them would probably relate to different technological objects, since these are what we encounter and use in our everyday lives. Many will probably suggest digital technological objects such as computers, mobile phones and other digital devices. However, technology is more than just the objects that we encounter and use. It may include the activity of making, in addition to using, technological objects, as well as knowledge and skills used in technological work for designing a technological object. Technology may also be an expression of will, i.e. the forces that drive technological work forward. The philosopher Carl Mitcham has summarised the ways of conceptualising technology in a framework where four aspects of technology are included: objects, activities, knowledge and volition (Figure 2).

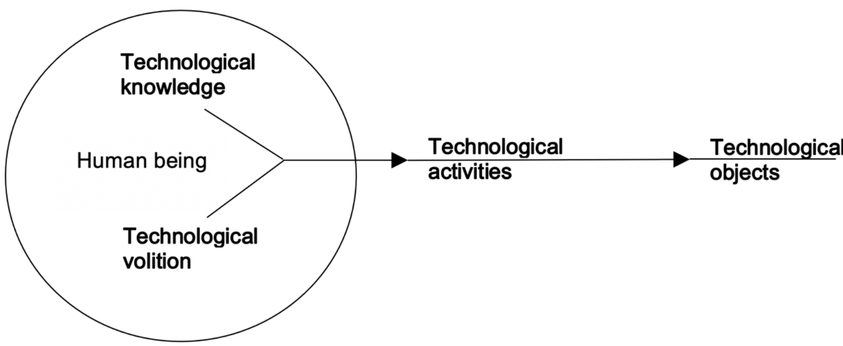

Figure 2 Mitcham's framework of technology based on the four aspects of technology

(Redrawn from Mitcham, 1994, p. 160)

Technology as objects is the most common, and probably also the easiest way, in which technology is conceptualised (Mitcham, 1994). The technological objects could be objects that we both make and use. Mitcham refers to some basic types of technological objects, such as clothes, utensils (e.g. dishes, pots), structures (e.g. houses), apparatuses (e.g. brick kilns, dye vats), utilities (e.g. roads, electric power networks), tools (manually operated instruments), machines that operate and produce products, and automated machines (e.g. a thermostatically controlled heater). Technology as activities can be the using or making of technological objects. Using technological objects can be referred to active use (e.g. using tools for creating new objects) or passive use (e.g. travelling by train). Further, Mitcham describes that the making of objects can involve activities such as inventing, designing, constructing or testing technological objects. Technology as knowledge is, according to Mitcham, the knowledge necessary for making and using technological objects. He suggests different types of technological knowledge: sensorimotor skills also knowns as "know how"; technical maxims such as rules of thumb; descriptive laws or technological rules based upon "empirical laws" derived from experience; technological theories which are scientific theories applied in real situations. Volition is the most subjective of the four aspects of technology. An individual's desire, will, motives, intention or choice affects what the outcome will be, in terms of technological activities and objects. Mitcham describes that volition may be seen as being based primarily on needs, such as a human's will to survive or to control nature to create a better life, but it may also be seen as a force beyond technological development work that does not address these primary human needs, but more the technological desire of humans. According to Mitcham, volition also involves ethical and moral analysis of technology, and the critical analysis of what effect technological objects will have on society, the environment or human beings.

As may be seen from Mitcham's conceptual framework of technology (Figure 2), human beings' volition together with their technological knowledge is what controls technological activities such as using and making technological objects. Although this seems like an easy-to-grasp picture of the relationship between humans and technology, this may not be the case. As mentioned above, most people consider technology to be using technological objects, especially modern digital technology (see Compton & Compton, 2013; Svenningsson, 2019). What we can learn from Mitcham's framework is that this way of seeing technology is in many ways alarming: if we only understand technology as objects that we use, without seeing or understanding the processes or knowledge hidden behind them, it will be difficult to critically analyse and evaluate them. We will end up as passive consumers (De Vries, 2005), in the hands of more knowledgeable people, who have their own will, desires and intentions regarding the technology. According to Stiegler (1998), this state is a consequence of the emerging imbalance in the relationship between humans and technology. Dakers (2019) argues that, despite the technologically textured world we live in today, there is ironically something lacking in the delivery of technology education: issues concerning the relationship between humans and technology are neglected in favour of making technological objects. Axell (2019) suggests that teaching should not focus only on how technology may be created, but that it is necessary to develop pupils' knowledge of the technology itself as well as to develop their ability to critically analyse it. These arguments give rise to reflections on the purpose of technology education, and why teaching and learning technology with respect to PTS is important. To this end, there is a need to examine the complex relationship between humans and technology.

The relationship between humans and technology

The question of why it is necessary to teach and learn technology with respect to PTS is as important to answer as the questions of what to teach and how to teach. Skolverket (2017) relates this issue to the aforementioned digital competence, which includes knowledge of how digital technology works and knowledge of its effects on everyday life, both at home and at work. From a technology education perspective, this issue may be interpreted in relation to the co-evolutional relationship between humans and technology suggested by Stiegler (1998), which can be described as having become 'de-phased' due to the rapid development of digital technologies (Dakers, 2019; Stiegler, 2010).

The co-evolution

The philosopher of technology Bernard Stiegler argues that the evolution of the human being was, and is, a result of the relationship between the human and technology (Stiegler, 1998). According to Stiegler, the relationship is complex and even if technology is an invention of the human, the relationship is co-evolutional; technological objects evolve and interact with humanity, and have always been an essential component for humans in surviving. Humans' intellectual, inventive and physical abilities have interacted with nature resulting in the development of technological objects such as flint tools for processing plant and animal materials. The development of these tools has introduced what Stiegler calls technological consciousness, which involves anticipation or foresight regarding the possibility of the tools, based on the interaction between the human's abilities and the tools. This, in turn, has introduced new technological objects and activities, and new anticipation. Hence, according to Stiegler, the co-evolutionary relationship between humans and technology implies that human culture, over time, has developed in pace with technology in a symbiotic way.

From the perspective of Mitcham's conceptual framework of technology (Figure 2), the human being's volition has been based primarily on needs such as the will to survive or to control nature to create a better life. Over time, volition has been affected by the anticipation of the possibilities of technological activities and objects. Based on the technological knowledge that humans have developed, technological activities such as using and making technological objects have become more innovative, where volition has become a subjective force that drives the using and making of technological objects, based on the human's desire rather than simply on human needs (Mitcham, 1994). Thus, anticipation and technological consciousness have evolved in a way where the co-evolution of the human being and technology has become de-phased (Stiegler, 1998). The de-phased relationship is caused by the rapid development of digital technologies and the decreased ability of humans to reason and critically analyse the technological objects that are made or used (Dakers, 2019; Stiegler, 2010). Seen from the perspective of Mitcham's framework of technology, using and making technological objects is based on the interplay of technological knowledge and volition. The way humans experience each of these will affect the outcome in terms of technological activities and objects. Thus, if humans are using, or making, technological objects without understanding the intentions or knowledge hidden behind them, it will be difficult to critically analyse and reason about them. The consequence may be that humans end up as uncritical consumers (De Vries, 2005), that is, they are not able to take into account the effects and consequences of the technology on their lives, on society and on the environment. Accordingly, technological knowledge is an important key to being able to understand, manage and evaluate technology, especially with respect to digital technology and the PTS that surround us in everyday life. The question is then: what is the knowledge hidden behind the technology, and what needs to be addressed in technology education to prevent the "black box" syndrome. To this end, technological literacy, and its origins in philosophy of technology, can provide us with answers.

Technological literacy in relation to PTS

Technological literacy is one of the primary goals of technology education and guides the educational content in teaching about technology (Nia & De Vries, 2016). However, it has been difficult to find a common definition of what educational content technological literacy encompasses, since the need for technological knowledge varies over time and also depends on the context in which you live (Hallström, 2011). Nia and De Vries (2016) developed a framework based on Mitcham's four aspects of technology and other philosophical perspectives on technology. Their aim was to use this framework to categorise concepts and concerns highlighted by other philosophers of technology and to use this as a tool for evaluating the educational standards for technological literacy that guide technology education, as presented in the International Technology Educators Association's Standards for Technology Literacy: Content for the study of technology (ITEA, 2007). Based on the evaluation, they concluded that the technological literacy framework should pay more attention to the specific design of artefacts with regard to their physical and intentional structure, and also that more attention should be paid to the knowledge aspect of technology. The knowledge aspect in technology education has also been highlighted by Axell (2019), who suggests that it is necessary to develop knowledge of the technology itself, in order to enable pupils' ability to critically analyse it, and to make informed decisions. Thus, technological literacy when it is understood as meaning being able to understand, manage, use and evaluate technology, implies that technology education involves more than just developing pupils' ability to make and use technological objects (Dakers, 2006, 2019). With regard to teaching and learning technology in activities such as analysing and designing PTS, this implies also focusing on the technological knowledge hidden behind PTS.

Technological knowledge with respect to PTS

Most people consider technology to mean using technological objects (Compton & Compton, 2013; Svenningsson, 2019). This is natural: technological objects such as computers, mobile phones and other digital devices are used by people both at home and at work, which has a great influence on their lives, probably even more than other technological objects have had in the past. However, to prevent the "black box syndrome" and avoid people ending up as uncritical consumers, the "using" perspective on technology need to be broadened. Other aspects of technology need to be made more explicit, where technology is not only seen as using the technological objects, but also seen as the knowledge and intentions hidden behind them.

Technological knowledge as conceptual and procedural

In technological work, when developing technological solutions and solving technological problems, specific technological skills and knowledge are necessary in order to be able to produce the technological solution. Based on the philosopher Gilbert Ryle's distinction between knowledge as "knowing how" and knowledge as "knowing that", Norström (2014) describes the necessary technological skills and actions as "knowing how". Further, Norström describes descriptive and prescriptive technological knowledge, such as components, algorithms, laws and rules, as "knowing that", which underpins the actions enabled by "knowing how". Norström's description of technological knowledge in terms of "knowing how" and "knowing that" is closely related to McCormick's (1997) definition of conceptual and procedural technological knowledge. McCormick describes conceptual knowledge as the understanding of technological concepts and how these can be linked to each other, and to a context. Further, procedural knowledge relates to being able to practically take on a technological task, or knowing how to do something, such as analysing, using or designing a technological object. Furthermore, McCormick (2004) suggests a third type of technological knowledge, qualitative knowledge, which is related to the specific context in which, for example, a technological problem is to be solved. Qualitative technological knowledge encompasses specific technological knowledge of interrelated concepts and processes necessary for solving specific problems in specific contexts. De Vries (2005) suggests that success in processes such as analysing and designing is based on the ability to make a fit between several factors, such as the phenomena involved, the available tools and materials, as well as the problem to be solved. These factors, which can be considered as contextual factors, encompass both conceptual and procedural knowledge necessary for being able to take part, proceed and succeed in these processes as part of specific contexts. Therefore, in technology education, when teaching and learning technology in processes such as analysing and designing PTS, it is important to be aware of, and to address, conceptual and procedural knowledge with respect to phenomena involved as part of the contexts in the activities.

Knowledge of the dual nature of PTS

When taking part in technological activities such as analysing or designing technological solutions, it is important to be aware of the dual nature of technological solutions, i.e. function and structure (De Vries, 2005). The function relates to human intentions and the need to change one state into another by means of the technological solution, and the structure is the appropriate physical structure of components for realising the function. This also involves an awareness of what makes the technological objects different from other physical objects and natural objects, i.e. they are made and used for realising goals based on human intentionality (Kroes & Meijers, 2006).

Understanding the dual nature of technological solutions involves four types of technological knowledge: knowledge of the physical nature, such as properties of the solution; knowledge about the functional nature, such as functions that will be fulfilled; knowledge about the relation between the structural and functional nature, such as setting up an appropriate physical structure of components to realise the function; and knowledge of processes, such as ways to turn structure into function (De Vries, 2006). Thus, understanding the dual nature encompasses both conceptual and procedural knowledge, and can also be related to Norström's (2014) description of "knowing that", for example, components, algorithms, laws and rules, as underpinning "knowing how", which enables actions such as analysing or designing. However, the various technological solutions we encounter in everyday life may be difficult to understand from a structural and functional perspective. A way to facilitate understanding of the structural and functional nature of a technological solution is to see it as a technological system (De Vries, 2005).

Systemic knowledge and systems thinking

Ropohl (1997) argues that to enable future citizens to take part in society in an informed and critical manner, it is necessary to have a socio-technological understanding about the complex relationship between technology and society. Socio-technological understanding is interdisciplinary, and encompasses systemic knowledge about socio-technological systems including the relationship between technological objects, social practice and the environment. There are three different interpretations of a system: the structural, i.e. as a set of parts and the relationships between the parts, the functional, i.e. the system as an entity where inputs are transformed to outputs as a function, and the hierarchical, when the structural is turned into subsystems (Ropohl, 1999). Further, Ropohl describes systems as human-made models that represent existing objects; hence, systems may be interpreted as cognitive maps of reality. This way of using systems as models facilitates understanding of the relationship between technology and humans in socio-technological systems by making the structural, the functional and the hierarchical aspects more explicit. Thus, systemic knowledge is applicable in understanding how digital technology affects humans, society and the environment, where knowledge about the technological solutions involved, as well as knowledge about the consequences that technology might have on humans, society and the environment, are important constituents. Further, the structural and functional natures of technological solutions may also be interpreted and understood as subsystems in a larger socio-technological system. This way of thinking about technological systems is referred to as systems thinking, which is based on three overarching abilities: understanding the parts of the system, understanding how the parts interact and understanding the system as a whole (Booth Sweeney & Sterman, 2007). Applying the systems thinking perspective to a technological solution may facilitate understanding of its structural and functional nature, i.e. seeing the structural nature in terms of a set of parts that interact, and the functional nature in terms of an entity where inputs are transformed to outputs (De Vries, 2005). Thus, systems thinking may be important in understanding how PTS work, both as single objects, and as parts of larger systems. Furthermore, systems thinking may also make the characteristics of the design process more explicit, i.e. by explicating the movement back and forth between functional and structural aspects (De Vries, 2019). However, the nature of PTS is different in comparison with traditional technological solutions since there is also input and output in terms of information which needs to be taken into account in processes of analysing and designing.

The nature of PTS in terms of inputs and outputs

Traditional technological objects such as clothes, utensils, apparatuses, tools and machines, require input based on matter and energy (Mitcham, 1994). According to Mitcham, this input may come from humans, animals, nature or external technological objects, such as machines, which produce electricity to drive and control mechanical movements. However, modern technological objects such as PTS are based on digital technology that also has an immaterial character that requires an input of energy. Mitcham describes this energy as not primarily based on bodily or mechanical movements but on digital movements, a flow of information. In traditional mechanical technological objects, the input is based on energy that results in an output of determined motions and behaviour. In PTS, in addition, an input of information results in a pre-determined output of information which controls the behaviour. That is, the inputs and outputs are based on an immaterial component, i.e. digital information in terms of a code that controls the function. By using a systems thinking perspective, the PTS may be seen as a technological system where components interact with each other, and programming is used to control the components and the flow of information between them. The program can be seen as an immaterial component that includes information, stored in a material component, the processor. The other components in the PTS, such as buttons, sensors and speakers are connected to the processor. The components handle the flow of information based on how they work, and what is written in the code. Hence the code includes information about how each component will behave and function in the PTS. The components are structured in a way that enables them to interact and allows information to move between them to fulfil the function of the PTS. By using models, PTS can be made easier to understand (see Ropohl, 1999). Below is a model of a PTS, the micro:bit design "the burglar alarm" that represents the PTS that are used in the empirical studies of this thesis (Figure 3).

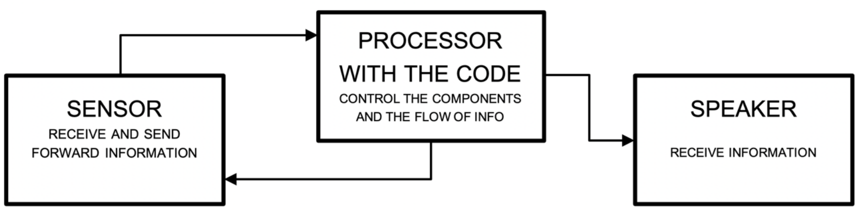

Figure 3 Model of a PTS, the burglar alarm

The model illustrates a closed-loop system where feedback is used to control the PTS. When a feedback signal (information) is sent from a sensor to the processor, a process is started. The process is controlled by the code in the processor, based on a conditional, which compares whether the condition is met or not. If the condition is met, a signal (information) is sent to the speaker, where the function of the system is fulfilled.

In technological processes such as analysing and designing PTS, the ability to understand inputs and outputs implies having technological knowledge to interpret and control flow of information (Mitcham, 1994). This ability may be related to cybernetics, knowledge of control.

Interpreting and controlling a flow of information

Cybernetics is knowledge about communication and control in the human and in the machine (Wiener, 1961). Norbert Wiener introduced an interdisciplinary theory synthesised from information theory, feedback and digital technology. The theory is based on the study of controlling information in systems with feedback loops where states of information interact with each other to produce predetermined behaviours (Mitcham, 1994). According to Wiener (1961), the function of a system, which may be a social, a biological or a mechanical system, depends on the flow of information that is sent and responded to in a feedback loop. Against the background of technology, Mitcham (1994) describes digital technological objects, i.e. PTS, as cybernetic devices that can not only be conceived of as a closed mechanical chain but also as a closed information chain. Today, many of the technological objects in our daily life are PTS, e.g. traffic lights, cars, remote controls, alarms, thermometers, and also larger systems such as water supply systems and electrical power systems, which can be conceived of as feedback controlled systems. Common to all these are that we now need an expanded technological knowledge to understand and control PTS, i.e. knowledge of programming.

Programming as a constituent of understanding PTS

When making a PTS work the way you want, programming is used to control the components and the flow of information between them. Thus, programming the PTS means that instructions are written by using a programming language that the processor can understand, and that by combining functions, operators and variables, the PTS is controlled to behave in an expected way. However, a prerequisite is that the person who writes the instructions can handle the syntax and semantics of the programming language, as well as understand how different sequences may be put together to achieve the desired behaviour of the PTS, i.e. that they are able to program.

Learning programming

In order to be able to analyse or to control a PTS, pupils need to learn a certain amount of programming. The research on teaching and learning programming with respect to PTS in technology education is limited, although programming taught as its own subject, i.e. computer science, has been more widely investigated, both at university level and at compulsory level. However, many of the studies at compulsory school level direct attention to computational thinking, both defining what it is, and how to teach and learn it. Although research has made efforts to define computational thinking, little consensus has been reached (Grover & Pea, 2013; Vinnervik, 2020). This is a challenge when considering computational thinking in relation to teaching and learning programming in compulsory school, i.e. it is difficult to organise teaching, as well as to assess learning, without knowing what is to be taught (Selby & Woolard, 2013).

Regarding learning to program at university level and upper secondary level, there are significantly more studies available. Several of these studies (e.g. McCracken et al., 2001; Robins et al., 2003; Rolandsson, 2015) show that students have difficulties in learning to program. Although there are differences between teaching adults programming, and teaching younger pupils programming as an element of teaching technology, we may assume that younger pupils would have similar difficulties (see e.g. Grover & Basu, 2017). However, we have not yet got a broad picture of pupils' experiences of learning to program at compulsory school level. Grover and Pea (2013) suggest the need for more empirical studies that investigate younger learners' experiences of programming, in order to identify the difficulties and what to address in teaching.

Although learning to program has only recently become part of several countries' curricula, it has sometimes appeared as content in compulsory school and later been removed. As far back as the late 1960s, Seymour Papert introduced the programming language Logo a so-called mini-language with a simpler syntax and semantics which was designed for younger learners. The purpose of Logo was to let younger learners use technology to control their world, and this was enabled by letting them learn to program. Papert emphasised programming as a means of knowledge construction that also was expected to change the way pupils learn in general (Papert, 1993). This is related to what is called computational thinking and its transfer effects when learning to program. However, in the early eighties, Pea (1983) investigated when pupils aged 8–12 were programming with Logo. The results show that even if pupils are able to use some programming concepts in a specific context, they have difficulties in reusing them in another context. In other words, pupils are not able to transfer understanding between contexts, which Pea suggests is a result of the fact that pupils do not develop a deeper understanding of the programming concepts involved in the activity. A more recent study by Grover and Basu (2017) shows that although pupils are introduced to visual programming by using blocks that contain ready-made code, which makes it syntactically easier to program, pupils still have difficulties understanding what the programming concepts represent. Moreover, Pea and Kurland (1984) suggest that learning to program involves more than just the semantics and syntax of the programming language, and that it is unreasonable to expect younger pupils to become advanced programmers given the amount of teaching time that is spent on programming in school. Pea and Kurland emphasise the difference in what students at university are able to learn and what pupils in compulsory school are able to learn, with respect to both the time aspect and to metacognitive ability.

The above studies show that learning to program is not easy, neither for adult students nor for younger pupils. There are of course differences in what students at university level are expected to learn, compared to what younger pupils in compulsory school are expected to learn. Further, in the study by Pea (1983), the younger pupils worked with simpler text-based programming, while younger pupils today encounter primarily visual programming in the form of block-programming. The block-based programming is expected to make it easier for pupils when learning to program (Kjällander et al., 2016) because they do not have to engage in the more difficult text-based programming. However, the semantical difficulties seem to remain even when using block-programming, and pupils have difficulties understanding what the blocks represent and how to use them (Grover & Basu, 2017). This, in turn, creates difficulties in using programming as a tool in technology development work.

Using programming as a tool in technology development work

In technology development work, programming may be seen as a digital tool to be used for controlling PTS (Skolverket, 2017). Being able to use a tool presupposes that the user has knowledge of the tool, and skill in handling the tool. In a previous study, Ginestié (2018) investigated how a digital tool such as programming affects teaching and learning technology. As part of the study, the pupils were expected to solve a technological problem by using programming to control a technological system. Thus, programming was used as a potential tool to solve the problem. The results show that pupils' ability to solve the problem is affected by how familiar they are with the tool. Therefore, pupils' ability to use programming becomes either an asset or a limitation depending on how previous teaching has been organised (Ginestié, 2018). This suggests that pupils should first learn to use programming as a tool to solve a technological problem. If the teaching instead aims to develop knowledge in programming at the same time as developing other technological concepts and processes in relation to solving the technological problem, there is a risk of the latter falling into the background, due to the difficulties of learning to program. Ginestié suggests that a large cognitive focus will be devoted to learning to program. As a result, there will be less focus on learning other technological knowledge. These issues are important to consider when teaching and learning technology in programming activities such as analysing and designing PTS using different programming materials.

Teaching and learning in programming activities

Many pupils encounter programming in teaching through practical activities with different programming materials such as Lego Mindstorms, BBC micro:bit and Arduino. These kinds of materials, also called tangible materials or Direct Manipulation Environment (DME), are considered to provide opportunities for pupils to learn technological concepts and processes (Krumholtz, 1998; Barak & Zadok, 2009). In a previous study, Ivarsson (2003) investigated this kind of practical activity where pupils in 6th grade were working with a problem-solving task using the programming material Lego Dacta. The study showed that the pupils were able to solve rather advanced problems with the support of the visual and interactive aspects of the programming material. However, when pupils were presented with a similar problem in a new context, they were not able to solve this problem. Ivarsson suggests that the pupils did not develop an in-depth understanding of central concepts in the first activity that could take them further, beyond the context of that specific teaching activity. These findings are similar to the results in the study by Pea (1983), i.e. that the pupils gain no deeper understanding of concepts, and hence, have difficulties in reusing them in another contexts. Ivarsson (2003) suggests that pupils' attention is mostly directed to the practical activity, and not to learning theoretical concepts to be used beyond the activity. Further Ivarsson describes the risk when teachers, as may happen, get the impression that pupils have a deeper understanding of theoretical concepts, since they demonstrate a practical ability to handle problems and are using a way of communicating that is understandable in relation to the context. Hence, the teacher believes that the pupils understand a theoretical concept or phenomenon in the same way as the teacher does. Ivarsson criticises the expectation that pupils gain a deeper understanding of theoretical concepts only by practical experience of complex processes in programming activities. It is not enough to only offer programming material; pupils cannot discover the underlying principles of programming that are embedded in the material on their own. Pupils need guidance from a teacher who takes them beyond the practical activity (Ivarsson, 2003; Lye & Koh, 2014; Pea, 1983). Consequently, programming activities need to go beyond being only explorative and fun events, and instead be aligned with the curriculum; otherwise, there is a risk of the outcome of the activities being fragmentary in terms of learning (Vinnervik, 2020). An important issue regarding the organising of teaching is whether knowledge of concepts and phenomena may be seen as required in order to be able to tackle problems during the programming activity, or whether the knowledge is an expected learning outcome from the programming activity (Slangen et al., 2011). This points at the importance of investigating pupils' understanding and experience of concepts and phenomena in programming activities. There is a need for more research about what they learn, and how they learn this, as well as what is necessary to address before and during the activity.

Teaching and learning technology in activities such as analysing and designing PTS with different programming materials, needs to be organised in alignment with the aims and content in the technology syllabus. This includes learning of central technological concepts and processes that take pupils beyond the practical activity, not only in relation to being able to program, but also in relation to the other technological knowledge involved. Therefore, programming needs to be investigated and understood in relation to what technology education is, as well as adapted to what technology education is expected to deliver in terms of learning, based on the ways pupils perceive the content. A few studies have directed attention to these issues, and they are presented in next section.

Previous research on pupils' perceptions of PTS

Research regarding pupils' relationship to subject-specific content in technology education is quite limited. In the last decade, however, more research has been conducted in this direction (see e.g. Björkholm, 2015; Koski & De Vries, 2013; Svensson, 2011). There are also a few studies that have investigated pupils' perceptions of PTS in processes of designing them.

Slangen et al. (2011) investigated what pupils, aged 10-12, can learn by working with robots, i.e. PTS. Based on previous research, they first identified four levels of how pupils perceive robots (Slangen et al., 2011, p. 453):

- Psychological perspective: Robots are animated creatures. Pupils attribute characteristics to the robots, such as intention, consciousness, emotion, volition, or reflexes, or they mention limbs or organs, implicitly referring to these attributes.
- Technological perspective: Robots are man-made devices that are able to act. They contain technological components, are made of special matter, and function according to technological processes such as mechanical and programmed processes.
- Function perspective: Robots are man-made devices that are able to perform intended functions in order to solve a problem or to satisfy a need.
- Controlled system perspective: Robots are man-made devices that are able to interact autonomously with the surroundings based on a pre-defined program or by means of remote control. Part of this is the "Sense-Reason-Act" loop (S-R-A loop).

Based on the above perspectives, Slangen et al. (2011) planned and conducted a number of lessons where pupils were designing robots with Lego Mindstorms, a programming material that includes Lego, sensors, motors etc. The aim was to investigate pupils' understandings of robots, and how their understandings develop during the design activities. The results show that the pupils initially use the psychological perspective to describe robots, which then develops towards the technological perspective as they were being taught. Initially, they use words that can be related to human behaviour, but their use of concepts develops during the design activities with the support of the teacher, and the pupils eventually reach the functional perspective where they perceive that robots can perform intended functions to solve problems. However, the results show that pupils have difficulties reaching the controlled system perspective. Slangen et al. suggest that pupils do not consciously use systems thinking when working in these kinds of design activities, but they have the ability to reflect on individual components of the system if they are encouraged by the teacher. From the study, the progress from the psychological perspective to the controlled system perspective seems to be a challenging step, where pupils move from initially perceiving robots as animated creatures to eventually perceiving them as man-made devices controlled by a S-R-A loop (i.e. feedback control). Even though they were taught about the concept of control, they had difficulties realising a control function in terms of a S-R-A loop. Slangen et al. conclude that to be able to control robots with programming, pupils need to learn about the components of the system and the functional relationships between the input (e.g. sensors), the program, and the output (e.g. motors). Thus, in order to design a robot, pupils need to have knowledge of programming concepts and systems thinking skills.

In another study, Mioduser et al. (1996) investigated Grade 6 pupils' perceptions of the control process, and their knowledge of components, in the context of instructional use of programming materials. The pupils were taught about automated systems and were working on designing an automatic door, for 12 lessons in total. The material consisted of Lego with components such as motors, sensors, lamps, gears etc., and Logo programming was used for controlling the door. The collected data consisted of a pre-test, worksheets, pupils' drawings and constructions, and an interview that was held while the pupils were testing their construction. In the analysis, four qualitative models of how pupils perceive the control process were identified (Mioduser et al., 1996, p. 371-373):

- Black box: Describes an overall behaviour of the system which indicates that in the presence of an input, an output is produced. However, structural and functional aspects are ignored, as well as how the output is generated.
- Reactive: The sensor functions are distinguished and activated components are mentioned, but the system is primarily perceived as sensing-acting, i.e. the sensors communicate directly with other components.
- Switch: Awareness of the need for a control function that instructs the activated components to perform actions. However, the nature of the control function is undefined.
- Control: Understanding the structural aspects of the system, and how the function is controlled by an action chain, defined by what is programmed in the computer.

The results showed that the students had difficulty understanding the control process, and the chain of control functions: only 3 out of 19 pupils reached the fourth level, Control. Mioduser et al. (1996) suggest that pupils do not understand the control process since they lack knowledge of how the components work and how they affect the whole system. Mioduser et al. provide the example of pupils' misconceptions regarding sensors. Several pupils did not understand how sensors are affected by changes in the environment, and that they send signals to the computer. They perceived that the sensor sent a signal directly to the motor and excluded the role of the computer in the system, even though they had written a program to handle the signal from the sensor and to deliver information to the engine. The pupils had difficulties understanding feedback control as well as the flow of information in the system, and Mioduser et al. suggest that the handling and control of the flow of information is the most difficult thing for pupils to understand when they work with this kind of design activity. Mioduser et al. conclude that even if the pupil is aware of the need for the control function and can identify its presence, it does not necessarily mean the pupil has an ability to understand or describe the control function in terms of how the system processes information. This study, together with the study by Slangen at al. (2011), indicates that pupils have difficulties conceptualising the structural and functional nature of PTS. Accordingly, there is a need for more research that provides in-depth knowledge about what to address in teaching in order to overcome these difficulties, as well as knowledge about what enables learning in situations involving analysing and designing PTS.

Summary

The way we conceptualise technology will affect technology education and its educational content. It is important to not lose contact with what technology is and what technology education should be. Hence, this thesis takes its point of departure in technological literacy, and its origins in philosophy of technology, when reflecting on key elements in teaching and learning technology with respect to PTS. Mitcham's four aspects of technology direct attention to what technology is, and how the co-evolutional relationship between humans and technology has been de-phased, based on a decreased understanding of the technology itself (Stiegler, 1998). We have ended up as uncritical consumers of the (digital) technology that surrounds us in everyday life (De Vries, 2005). To prevent this so-called "black box syndrome", the "using-perspective" on technology needs to be broadened to include the technological knowledge hidden behind the technology. The elements of technological knowledge considered as important in this context are: systemic knowledge and systems thinking; conceptual and procedural knowledge in relation to processes of analysing and designing PTS, such as knowledge of the functional and structural nature of PTS, and knowledge about how to interpret and control a flow of information. This includes knowing how to program, i.e. handling the syntax and semantics of a programming language in order to achieve an expected behaviour from the PTS. Consequently, there are many parts that it is necessary to understand in processes of analysing and designing PTS.

However, simply defining key elements to address in teaching and learning on the basis of the knowledge domain of PTS is not sufficient. When the content of PTS is transformed into teachable content based on the requirements of the technology syllabus, it is also necessary to take into account the pupils' relationship to the content (Bronäs, 2016). Previous research shows that learning is not an automatic outcome in teaching activities where pupils analyse and design PTS (see e.g. Ivarsson, 2003; Pea, 1983). Pupils have difficulties conceptualising structural and functional relationships, and have difficulties interpreting and controlling the flow of information, i.e. understanding and using programming to control PTS (Mioduser et al., 1996; Slangen et al., 2011). However, previous research does not provide us with answers regarding what enables learning in situations involving analysing and designing PTS, and what to address in teaching in order to overcome pupils' difficulties. There is need for more in-depth research about how pupils' develop understanding of PTS in situations involving analysing and designing PTS. To this end, the three empirical studies in this thesis take the phenomenographic perspective on learning, and investigate the ways pupils experience PTS in the processes of analysing and designing. In the next chapter, the premises and theoretical assumptions that underpin phenomenography will be described, and set in relation to the empirical studies.

Chapter 3: Phenomenography

In this chapter, the premises and theoretical assumptions that underpin phenomenography will be described in relation to the research interest of the thesis. First, the phenomenographic research approach is introduced. This approach is based on empirical investigations of learners' qualitatively different ways of experiencing a phenomenon, which shed light on learners' experiences of the part-whole structure of the phenomenon, and allow the identification of critical aspects, i.e. the aspects that are necessary for the learners to discern in order to understand the phenomenon. This is followed by an introduction to the idea of critical aspects as key elements in teaching and learning situations, using variation theory as a model for learning. Next, the terms relevance structure and contextual appreciation are introduced, in relation to both situations involving investigating learners' ways of experiencing a phenomenon, and teaching and learning situations. Finally, the premises and theoretical assumptions are summarised in relation to how phenomenography is used in the empirical studies in this thesis.

The phenomenographic approach

Phenomenography was developed in the early 1970s by Ference Marton and his colleagues at the University of Gothenburg to study and describe how individuals understand and experience different phenomena. Initially, the aim was to empirically analyse different ways of experiencing phenomena in order to understand the part-whole structure in the ways of experiencing. Later, the focus moved towards methodology (see e.g. Marton, 1981, 1986). Over the years, the phenomenographic tradition has further developed. An understanding of the different ways of experiencing the part-whole structure was assumed to have a pedagogical value, derived from the idea that if learners become more aware of the relationship between the parts and the whole, this leads to a more powerful way of experiencing the phenomenon. Based on this assumption, a theoretical perspective on learning was developed, underpinned by awareness of the part-whole relationship, which is addressed in *Learning and Awareness* by Marton and Booth (1997). In this book, a pedagogy of awareness was further developed which directed attention to teaching and learning situations. Principles of teaching were introduced that aim toward developing learners' capability of experiencing phenomena in a more powerful way. These principles relate to the idea that variation in relation to important aspects of a phenomenon can provide opportunities to develop learners' capability of experiencing a phenomenon. Marton & Booth describe this by saying that the teacher is building a certain relevance structure in which aspects of the situation appear as more or as less relevant, i.e. bringing forward some aspects to be focused on and putting others into the background, in order for learners to experience the phenomenon in a powerful way. Hence, the relevance structure indicates a certain way of experiencing the phenomenon. In *Learning and Awareness* (Marton & Booth, 1997) and later on in other studies (see e.g. Lo, 2012; Marton, 2015), the building of certain relevance structures to develop learners' ability to experience phenomena has been established as a model of learning. This is based on the assumption that experiencing variation is necessary for discernment, and that discernment is necessary for learning. However, building certain relevance structures that indicate a powerful way of experiencing a phenomenon implies directing attention to important aspects of the phenomenon. This requires knowledge of what the important aspects are. By investigating learners' qualitatively different ways of experiencing a phenomenon, phenomenographic studies can provide answers regarding what the important aspects are.

In phenomenographic studies, the research interest is in the variation in learners' ways of experiencing the same phenomenon. By investigating the qualitatively different ways of experiencing a phenomenon, critical differences between ways of experiencing can be identified. The critical differences indicate important aspects of the phenomenon that can be used in teaching for building certain relevance structures that enable learning. Marton and Booth (1997) describe these important aspects as critical aspects of the phenomenon that are necessary to discern in order to experience the phenomenon in a more powerful way. Further, discerning several of the critical aspects simultaneously implies that the phenomenon is experienced in a more complex and powerful way than before. Thus, from a phenomenographic perspective, learning implies expanding the ability to discern critical aspects, based on the idea that when something is learned, there is a change in the relationship between the learner and the phenomenon, i.e. the learner has developed an ability to experience the phenomenon in a more powerful way when it appears in new situations.

Therefore, the central focus in phenomenography is to investigate and describe the variation in learners' ways of experiencing a phenomenon, in terms of the way the phenomenon appears to the learner in a specific situation, e.g. in an interview or a teaching situation. Thus, the research interest in phenomenography is not directed to the phenomenon as such, but at how the learners experience the phenomenon, i.e. a second-order perspective is taken that forms the basis for the categories of description (Marton & Booth, 1997). Further, for Marton and Booth, the premise is that the descriptions are non-dualistic, i.e. the descriptions of experience are neither psychological (i.e. internal) nor physical (i.e. external), but are descriptions of the internal relationship between learners and a phenomenon. This implies descriptions of experience as constituted in the relationship between the learner and the phenomenon.

A main assumption in phenomenography is that there are a limited number of qualitative ways of experiencing a phenomenon. The research focus is on the qualitative differences in experiences and what aspects come into learners' awareness simultaneously, rather than on the richness of individual experience (Trigwell, 2006). The aspects that come into learners' awareness are referred to as the structural and referential aspects of the phenomenon (Marton & Booth, 1997). The structural aspects can further be described as relating to the discernment of the whole of a phenomenon within the context (the external horizon), as well as discernment of parts of the whole, the relationships between the parts, and how the parts relate to the whole (the internal horizon). These are closely intertwined with the referential aspect, which Marton and Booth describe as the meaning of the phenomenon, i.e. we have to see the phenomenon as some particular thing that is assigned a meaning. When a phenomenon appears in a situation, we experience it through our senses, in terms of what is present to us, by means of our perceptions of the parts of the phenomenon, i.e. by seeing, smelling and hearing. We are also able to experience the whole of a phenomenon from parts that are appresent (i.e. not present), which are in our awareness based on previous experiences. Marton and Booth provide the example of looking at a tabletop from above, where even if we only see the surface of the table, we are able to imagine the legs of the table based on our previous experiences of tables in general. Thus, even if the table is only partially present to us in a particular situation, we are also able to experience the whole of a table by means of parts that are appresent. Marton and Booth clarify the meaning of appresentation as: "…the fact that although phenomena are, as a rule, only partially exposed to us, we do not experience the parts as themselves, but we experience the wholes of which the parts are parts." (Marton & Booth 1997, p. 100). Thus, a learner's awareness of structural and referential aspects, both as present and as appresent, characterises the way the learner experiences a phenomenon. Hence, learners experience the phenomenon in different ways based on what aspects they hold in their awareness simultaneously, and depending on how many aspects are discerned, the way of experiencing can be considered as more or less powerful. Further, Marton and Booth suggest that the way of experiencing is dependent on previous experiences of the phenomenon from other situations, where learning involves the ability to relate the present experience to previous experiences.

Phenomenographic research aims to describe the qualitatively different ways of experiencing a phenomenon. The different ways of experiencing are characterised in terms of how many aspects of the phenomenon a learner is capable of discerning and having in focal awareness simultaneously (Marton & Booth, 1997). However, even though the learner is the starting point in phenomenographic studies, the investigation is not directed to the individual learner's experience per se. The main research interest is the variety of possible ways of experiencing in a group of learners. Marton and Booth describe this by saying that the learner's experience contributes to the variation within the whole group at a collective level. Hence, it is the result of the whole group that is analysed, where the descriptions of the different ways of experiencing the phenomenon are sorted into internally related categories of description. Thus, the categories of description capture the qualitative differences in ways of experiencing the meaning and structure of the same phenomenon in a group of learners. The range of possible ways of experiencing is referred to as the outcome space, which Marton and Booth describe as "…the complex of categories of description comprising distinct groupings of aspects of the phenomenon and the relationships between them" (Marton & Booth, 1997 p. 125). Further, the variation within the outcome space can be organised in a hierarchical structure with increasing levels of complexity, based on how many aspects of the phenomenon are in focal awareness simultaneously. Hence, critical differences between the categories can be identified, i.e. the critical aspects of the phenomenon can be identified.

By comparing the phenomenographic approach to other research approaches, Trigwell (2006) summarises the essence of the phenomenographic approach as taking a non-dualistic, qualitative, second-order perspective, where the aim is to identify key aspects (i.e. critical aspects) in the variation of learners' collective experience of a phenomenon, which results in a set of hierarchical categories of descriptions that are internally related. The qualitative differences captured by the categories of descriptions, based on what critical aspects the learners have discerned, indicate more or less complex ways of experiencing a phenomenon, in terms of its whole and its parts, which may be both present and appresent (Marton & Booth, 1997). As mentioned above, the ability to discern the critical aspects of a phenomenon implies seeing the phenomenon in a more powerful way, i.e. discernment of critical aspects is necessary for learning to take place. Thus, the results from phenomenographic studies, in terms of critical aspects that are necessary to discern, can inform teachers of what to take as their point of departure when building certain relevance structures in teaching and learning situations.

Critical aspects as key elements in teaching and learning situations

In the book *Necessary Conditions of Learning* (2015), Marton suggests that what is to be learned in a teaching and learning situation can be formulated in three ways, with increasing precision: in terms of content, in terms of educational objectives and in terms of critical aspects. Marton provides the example of photosynthesis as a content to be learned. However, focusing on the content of photosynthesis does not tell us what the pupils are expected to become able to do. Therefore more precision is necessary in terms of educational objectives. In relation to the example of photosynthesis, Marton suggests that the educational objective could, for example, be that pupils should be able to discuss how energy is stored through photosynthesis. Thus, the educational objectives encompass specified learning targets that inform both teachers and pupils what the pupils are expected to be able to do after the lesson or course.

However, to stage a teaching and learning situation with educational objectives in relation to, for example, photosynthesis, does not necessarily result in pupils mastering the educational objectives. The educational objectives do not say what the pupils are expected to understand in order to learn, and how they will be made aware of, and take into consideration, the necessary aspects of what is to be learned (Marton, 2015). In order to learn content and master educational objectives related to the content, i.e. to meet the learning targets, pupils must learn to discern the necessary aspects and keep them into awareness simultaneously. Marton describes the necessary aspects as constituent aspects of the whole (i.e. what is to be learned) that are necessary for the whole to appear. He provides the example of how awareness of what happens to the energy from the sun when reaching earth is a necessary aspect for understanding photosynthesis. Further, Marton states that if the pupil has not yet discerned this specific necessary aspect, it is a critical aspect for the pupil. Accordingly, this critical aspect is one of the things the pupil has to learn in order to meet the educational objective.

The didactical tetrahedron (Figure 1 in Chapter 1) shows the complexity of the relationships between the factors involved in teaching and learning situations. Initially the content is to be identified on basis of the knowledge domain to which it belongs. The identified content is then transformed by the teacher into teachable content based on requirements in the syllabus, by taking into account pupils' relationship to the content and to the teaching material used (Bronäs, 2016). As can be seen from Marton's (2015) reasoning regarding what is to be learned in teaching and learning situations, the different levels of precision relate to the complexity of the relationships in the didactical tetrahedron, and the importance of taking into account these different perspectives when analysing opportunities for content to be taught and learned. The content is taken as a starting point, as defined in relation to the knowledge domain to which the content belongs. By combining the content with what pupils are expected to be able to do with the content, the educational objectives are formed. In order for pupils to meet the educational objectives, they need to be aware of the necessary aspects of the content, some of which are critical for the pupils to discern in order to learn. Thus, in order to teach a content, and enable pupils to learn, teachers need to have content knowledge as well as knowledge of pupils' different ways of experiencing the content and what is critical for the pupils to discern. By investigating the relationship between pupils and a specific content, phenomenographic studies can inform teachers of what is to be learned in terms of critical aspects.

The results from phenomenographic studies, in terms of the identified critical aspects, can inform teachers of what to take as a point of departure in teaching situations, as well as being used in future studies, particularly those that use variation theory to design teaching that develops learners' capability of discerning critical aspects of phenomena. Variation theory is based on the same theoretical assumptions as phenomenography, but has a different research focus. In phenomenography, the focus is on the different ways learners experience a phenomenon, and the critical differences between these ways of experiencing. In variation theory, the focus is instead on theoretically informed principles of instructional design in situations involving teaching and learning of a phenomenon, which is referred to as an object of learning (Marton, 2015; Åkerlind, 2015). Variation theory aims to design teaching activities that expand learners' awareness of critical aspects of a phenomenon by introducing systematic variation in relation to the critical aspects (Åkerlind, 2015). Thus, the critical aspects are considered as key elements when providing necessary conditions for learning. In teaching and learning situations, this implies that the teacher builds certain relevance structures by letting learners experience patterns of variation concerning the critical aspects (also referred to as dimensions of variation) (Marton & Booth, 1997; Marton 2015). The variation is expected to develop learners' ability to discern critical aspects of the phenomenon. Marton describes this as "... moving the experience from an undifferentiated whole, through differentiation and integration, towards a differentiated and integrated whole." (2015, p. 53). The ability to discern also includes being able to recognise the meaning of critical aspects in relation to each other, and to experience their holistic relevance, which includes taking the context into account (Ingerman et al., 2009). That means that learners experience a situation as a whole in which the phenomenon is one part. Thus, as Marton and Booth (1997) suggest, the learner's way of experiencing a phenomenon is affected by the situation in which the phenomenon appears. Further, the ability to discern critical aspects of the phenomenon, and recognise their meaning in relation to each other and to the whole, is dependent on the relevance structure of that situation. Accordingly, the way a learner responds to a learning situation is dependent on how the relevance structure of the situation is experienced (Lo, 2012). This implies that in teaching and learning situations, the teacher stages situations where a certain relevance structure is built, to develop the learners' ability to discern critical aspects of a specific phenomenon. However, to be able to stage these situations, the teacher needs to be aware of what the critical aspects are, as well as to be aware of the extent to which the context of the situation provides access to the critical aspects to be discerned.

The relevance structure and appreciation of context

When teachers stage teaching and learning situations in subjects such as physics and technology, it is common to provide a variety of different contexts such as representations, tools and activities to visualise and facilitate understanding of phenomena (see Airey & Linder, 2009). Examples of these are models, pictures, measuring equipment, tangible teaching materials, and practical work including analysing and designing. What is common to these is that they all bring contextual factors to the situation which affect the relevance structure experienced by the learner, i.e. the contexts indicate a certain way to experience the phenomenon (Marton et al., 2004). This implies that when using contexts such as representations, tools and activities to visualise phenomena in teaching and learning situations, as well as in phenomenographic research which investigates learners' different ways of experiencing a phenomenon, contextual awareness is necessary. This means being aware of both the way of experiencing and what is experienced in relation to a phenomenon in a specific context (Marton & Pang, 1999).

Marton and Booth point out that: "Not only is the situation understood in terms of the phenomena involved, but we are aware of the phenomena from the point of view of the particular situation." (Marton & Booth, 1997, p. 83). This implies that contextual factors affect the experienced relevance structure of the situation where meaning and structure of a phenomenon are derived from parts in the context in which the phenomenon appears for the learner. Thus, in situations involving investigating learners' experiences, or in teaching and learning situations, it is necessary to be aware that a phenomenon is embedded in a context which lends meaning to how the phenomenon is experienced (Adawi et al., 2001). In the book *Classroom Discourse and the Space of Learning*, Marton and Tsui (2004) point out that for everything that learners are expected to learn, there are specific conditions that are necessary for being able to learn these things. Marton and Tsui start from the necessity of discerning the part-whole relationship, and of discerning the whole within its context (see Marton & Booth, 1997). However, they further add that it is equally important to discern the way the whole relates to the context, that is, the context shapes the discernment of the part-whole relationship, based on the way the whole relates to the context (Marton et al., 2004). Thus, contextual factors are of importance, both in teaching situations where learners are experiencing a phenomenon, as well as in situations where learners' ways of experiencing a phenomenon are investigated. Consequently, this poses important questions such as what contexts allow critical aspects of the phenomenon to be brought to the fore, and to what extent are learners able to develop certain ways of seeing the relevance structure in relation to the contexts. Therefore, when investigating ways of experiencing a phenomenon which is embedded in contexts such as representations, tools and activities, the contexts should be taken into account. The results will then not only contribute knowledge of how a phenomenon is experienced, but also how it is experienced in relation to specific contexts.

In situations where learners' ways of experiencing are investigated, as well as in teaching and learning situations in general, the learners constitute the meaning of a phenomenon based on previous experiences of the phenomenon and from the context of the situation. However, the learners also bring previous experiences of the context to the situation, which affect the discernment of the part-whole relationship, and its relation to the context (Tsui, 2004). Airey and Linder (2009) suggest that lack of previous experience of the context will make it difficult for pupils to be aware of appresented parts, i.e. to see beyond the parts that are present, and as a result, there will be difficulties in experiencing the phenomenon as a whole. Consequently, as Adawi et al. (2001) suggest, in situations in which a phenomenon appears, such as, for example, situations where learners' experiences are investigated, learners need to be provided with contexts that afford important aspects of the phenomenon, and learners should be familiar with the contexts that are provided. Therefore, when planning a phenomenographic study, it is necessary to delimit the phenomenon and determine what constitute important aspects of the phenomenon, as well as to identify situations where the important aspects of the phenomenon appear. Adawi et al. argue for the use of prepared contexts, which implies that the researcher identifies situations where the context is familiar to the learners, in which the phenomenon can be highlighted and become the focus of attention in such a way that the learner can express the experience of the phenomenon. Further, Adawi et al. describe the prepared contexts as specific objects or situations that the researcher considers as relevant for the learner to make sense of the phenomenon. Thus, the prepared context can be understood as a representation of the phenomenon that provides a certain relevance structure.

Phenomenographic studies commonly investigate learners' experiences by using semi-structured interviews in which questions are asked that direct attention to the phenomenon. However, learners' experiences can also be investigated by analysing their actions and discussions when carrying out a specific task (see, for example, Nyberg & Carlgren, 2015; Björkholm, 2015). Thus, if researchers can stage situations, such as interviews or tasks, in which learners' experiences of a phenomenon are expressed in discussions and actions in relation to specific objects or processes that represent the phenomenon, this will increase the potential for capturing the variation in ways of experiencing a phenomenon (Adawi et al., 2001). However, the situation in which the phenomenon is investigated, which is expected to be similar to teaching situations in which the phenomenon commonly appears, also indicates a certain way of experiencing the phenomenon in that specific context. The learners direct focal attention to certain aspects of the context which results in a certain way of experiencing a phenomenon (Marton & Booth, 1997), and the way of experiencing a phenomenon varies from situation to situation depending on its physical as well as its symbolic features (Marton, 2015). Thus, based on the assumption that learning is dependent on the relevance structure brought to a situation (Lo, 2012; Marton & Booth, 1997), contextual appreciation is necessary (Linder & Marshall, 2003). This implies that the results from investigations using prepared contexts similar to the ones used in teaching situations may not only inform us of the qualitatively different ways learners experience the phenomenon in these situations. The results may also inform us of what relevance structures are brought to the situations by the contexts in terms of relevant aspects, i.e. critical aspects, as well as irrelevant aspects, i.e. aspects that are not necessary to take into consideration (Pang & Ki, 2016).

Adawi et al. (2001) point out a distinction between the prepared context and the experienced context, i.e. the researcher needs to be aware of the discourse the study is based in, and what might be taken for granted when preparing a context, and be aware that the learner might experience the context in different and unexpected ways. Discourse in this sense is related to the discourse of the subject to be taught, where the phenomenon is expected to appear in specific teaching situations. Thus, considering that prepared contexts are based on contexts that are used in teaching situations, it is important to reflect on the discourse with regard to what is taken for granted in teaching situations, in relation to the ways learners experience the phenomena. Airey and Linder (2009) suggest that it is important to be aware of this so called "disciplinary discourse" which is characterised by the complex of tools, representations and activities within the discipline that are expected to facilitate learning. Fredlund et al. (2014) describe the use of disciplinary representations as a way to provide learners with access to important aspects of phenomena in physics in higher education. Parallels may be drawn to teaching technology and the use of activities such as analysing and designing PTS, as well as the use of programming materials that represent PTS, to facilitate learners' understanding of PTS. However, Fredlund et al. suggest that the use of the disciplinary representations also comes with challenges in teaching and learning situations. Teachers are so familiar with the disciplinary representations that they do not see what the learners are not able to see when interpreting the representations. Fredlund et al. consider this to be a result of not taking the learners' perspective when using representations in teaching. Teachers take for granted that the learners are able to discern parts of the phenomenon that are not present, i.e. appresent. Airey and Linder (2009) suggest that learners' ability to discern something that is not present is dependent on previous experiences of the representation, but also experiences from other representations of the phenomenon. They describe this as learning to decode different representations, and become fluent in moving between the different representations in the disciplinary discourse, to be able to holistically experience the represented phenomenon, as a result of which the understanding of the phenomenon increases. Something similar has been outlined by Marton (2006), who argues that in order to be able to generalise and transfer understanding of a phenomenon into new contexts, the learner needs to develop the capability to discern critical aspects of the phenomenon in different but connected contexts, where the learner uses the understanding based on the discerned critical aspects in order to see the differences and similarities between contexts.

Accordingly, in teaching and learning situations, a phenomenon should preferably be experienced in different but related contexts within the discourse of the subject to be taught, by means of representations and activities that bring certain relevance structures to the situation and provide learners with access to important aspects of the phenomenon. However, in order to be able to provide this, Fredlund et al. (2014) suggest the need to unpack the representations in order to give learners access to the important aspects of the phenomenon it represents, i.e. to provide conditions that direct learners' focus of awareness in a way that allows them to experience the phenomenon in a more powerful way.

In a previous study, Ingerman et al. (2007) investigate the characteristics of learners' focus of awareness and the relevance structure of the situation, when learning physics with the aid of computer simulation. The results show that the representational nature of simulations can be a powerful tool for bringing important aspects of phenomena into learners' focus of awareness. However, Ingerman at al. conclude that whatever tool is used to represent a phenomenon, the learning outcome is dependent on the congruence between the learners' focus of awareness, and the teacher's learning goals in the situation. Further, the teacher plays an important role in helping learners to unpack the representation so that learners can experience the phenomenon in a way that is not limited to the representation (Ingerman et al., 2007; Fredlund et al., 2014). Consequently, the use of specific contexts in teaching and learning situations brings certain relevance structures to the situations that indicate a certain way to experience a phenomenon. Thus, the choice of context is important, which implies that teachers should be aware of how the phenomenon appears for the learners in terms of what aspects are attended to, both relevant and irrelevant aspects. Otherwise, the context might not facilitate but instead constrain the learners' way of experiencing the phenomenon (Pang & Ki, 2016).

Summary of phenomenography in relation to the research interest in this thesis

Phenomenography has been developed in an educational context, and draws attention to the pedagogical value of identifying how learners experience a phenomenon, as well as identifying what learners need to experience in order to develop a more powerful understanding of a phenomenon, based on the part-whole relationship (Åkerlind, 2015). In phenomenography, learning implies developing a capability of seeing the phenomenon in a new way, different from the way it has been seen previously. Seeing in this sense implies being capable of discerning important aspects of the phenomenon. These important aspects are referred to as critical aspects, i.e. aspects that are necessary to discern in order to experience the phenomenon in a more powerful way (Marton & Booth, 1997). However, being capable of discerning the critical aspects of a phenomenon implies being capable of differentiating them from other aspects. In order to be capable of differentiating critical aspects from other aspects, situations need to be provided where the learner is presented with variation in relation to the critical aspects (Marton, 2015). In order to present this variation, the teacher needs knowledge of what the critical aspects are. To this end, phenomenographic studies can help with the question of what needs to be done by providing answers to the question of what is to be learned, i.e. the critical aspects. By analysing and describing learners' qualitatively different ways of experiencing a phenomenon, a set of hierarchical descriptive categories are created. These categories describe more or less complex ways of experiencing the same phenomenon based on the part-whole relationship and together are referred to as the outcome space (Marton & Booth, 1997. Within the outcome space, critical differences in ways of experiencing the phenomenon can be identified, i.e. the critical aspects of the phenomenon. The results can be used in teaching to build certain relevance structures, i.e. to bring forward some aspects to be focused on and put others into the background, in order for learners to experience the phenomenon in a powerful way.

However, in teaching situations, for example in subjects such as physics and technology, it is common to provide a variety of different contexts such as representations, tools and activities to visualise and facilitate understanding of phenomena (see Airey & Linder, 2009). Examples of these are models, pictures, tangible teaching materials, and practical work such as analysing and designing. What all of these have in common is that they all bring contextual factors to the situation which affect the experienced relevance structure of the situation, i.e. the context indicates a certain way to experience the phenomenon, where it appears with more or less relevance in relation to the context (Marton et al., 2004). Therefore, investigations of learning in terms of certain ways of experiencing a phenomenon also involve appreciation of the context (Linder & Marshall, 2003). Thus, in teaching and learning situations, as well as in phenomenographic research, there is need for contextual awareness with regard to both the experiencing and the experienced, regarding the specific ways learners experience a phenomenon (Marton & Pang, 1999). This implies being aware of which parts of the phenomenon are present and appresent, and which parts the learner is given access to by the representation. In order to provide necessary conditions that develop learners' ability to see critical aspects of the phenomenon, the teacher needs to be aware of what the critical aspects are, as well as being aware of the extent to which the context is able to bring the critical aspects of the phenomenon to the fore. Phenomenographic studies can inform teachers of what the critical aspects of a phenomenon are, by investigating learners' qualitatively different ways of experiencing the phenomenon in the contexts in which it is represented.

In the framework of this thesis, the research interest is to identify key elements to address in situations involving teaching and learning technology in processes of analysing and designing PTS. In order to achieve this, and according to the didactical tetrahedron (Figure 1) and Marton's (2015) reasoning about what is to be learned in teaching and learning situations, it is necessary to align two epistemological perspectives in order to provide pertinent teaching. This implies that the content is to be identified on basis of the knowledge domain to which it belongs, in term of what knowledge is important for pupils to learn, i.e. based on a first-order perspective. However, the content also needs to be taken into consideration from the perspectives of the pupils. To do this, the phenomenographic studies included in the thesis investigate pupils' qualitatively different ways of experiencing PTS. A second-order perspective is taken where the internal relationship between pupils and PTS is described, and critical aspects of PTS are identified in the context of the processes.

In the studies, pupils' different ways of experiencing PTS are investigated in the processes of analysing and designing PTS. The reason for choosing these situations is that in teaching technology, educational content with respect to PTS is commonly contextualised in activities such as analysing or designing PTS, usually by using representations of PTS such as different programming materials or PTS in everyday contexts. However, technological knowledge is by its nature context-bound (McCormick, 2004). That means that technological knowledge encompasses knowledge of interrelated concepts and processes that are considered necessary in specific contexts. Thus, in teaching situations where pupils experience PTS as a contextualised part in processes of analysing and designing, the nature of the knowledge involved is dependent on contextual factors such as the problem to be solved, the programming material used or other representations that might be used. Further, as Lo (2012) suggests, the contextual factors affect the pupils' experience of the relevance structure of the situation, and hence the way pupils respond to learning in the situation. Based on the assumption that the learning outcome is affected by the relevance structure of the situation (Ingerman et al., 2007; Lo, 2012; Marton & Booth, 1997; Marton et al., 2004; Marton, 2015), it is important to investigate pupils' ways of experiencing PTS as part of situations involving teaching and learning technology, i.e. in processes of analysing and designing. Therefore, attention should also be directed to the contexts in which PTS are experienced when investigating pupils' ways of experiencing PTS. That implies directing attention to PTS as contextualised in activities such as analysing or designing, where representations of PTS, such as different programming materials or PTS in everyday contexts, are used.

Therefore, the purpose of the phenomenographic studies in this thesis is to provide knowledge of how pupils experience PTS in the context of processes such as analysing and designing, using the programming material BBC micro:bit and technological objects representing PTS in everyday life. This includes empirical investigations of pupils' qualitatively different ways of experiencing PTS in order to understand the part-whole structure of the ways of experiencing, and how the contexts shape the experienced part-whole structure, as well as to identify what is to be learned in the processes in terms of critical aspects. The results of the empirical studies will form the basis for identifying key elements to address in teaching and learning technology in processes of analysing and designing PTS. In the next chapter, the research design for achieving this will be presented.

Chapter 4: Research design

The design of the three empirical studies included in this thesis is based on the assumption that the point of departure in all teaching needs to be taken from the way pupils experience the content to be taught. Therefore, the phenomenographic research approach has been applied, as the aim of this approach is to analyse and describe the qualitatively different ways pupils experience a phenomenon in situations in which it appears.

In order to answer the overall research question in the thesis, the results of the three studies have been synthesised, and framed by the knowledge domain of PTS, to provide improved interpretations of the findings in the individual studies. The synthesis is guided by the overall research question regarding what key elements are important to address in teaching and learning technology in processes of analysing and designing PTS.

The phenomenographic research process

In this thesis, the research interest is teaching and learning technology with respect to PTS. The empirical work focuses on pupils' relationship to PTS, in terms of variation in ways of experiencing PTS in situations such as analysing and designing. In order to be able to investigate the variation in possible ways of experiencing, it is necessary to provide situations where the phenomenon appears. This implies that I as a researcher stage situations such as interviews and activities which direct attention to the phenomenon. In the interviews and activities, data is collected from which pupils' experiences, as they are expressed by the pupils both in words and in actions, can be analysed by taking a second-order perspective. Thus, pupils' different ways of experiencing the phenomenon can be identified and described in a set of categories from which critical aspects can be identified. However, before starting this process, the research object needs to be delimited.

Delimitation of the research object

In this thesis, certain delimitations have been made in relation to the research questions that are asked. I have chosen to limit the content of the research questions to technological knowledge in relation to the phenomenon, PTS. The reason is that this is new and complex content in the compulsory school curriculum, and specifically in the syllabus for technology, that we need to gain more knowledge about. Another delimitation is the selection of the group of pupils who participate in the studies. I have chosen to study pupils aged 11–14 who have previously worked in various ways with PTS as part of their education. This is also the age group of students that I myself met during my time as a teacher and who I also presume to have the ability to express their understanding of PTS. I therefore consider them as possible respondents in the studies.

When studying a specific phenomenon with the phenomenographic approach, the phenomenon should be delimited to try to ensure that the pupils express their experience of the phenomenon that is chosen by the researcher. I have limited the research to technological knowledge, within which I have chosen to focus on knowledge of PTS, both in situations involving analysing existing PTS, and in situations involving designing and coding new ones. Since both programming and technological solutions can be difficult to clearly define because of their complexity and substantive connection to several different areas, I have used prepared contexts (see Adawi et al., 2001) to frame what is meant by PTS within the thesis. The aim with the prepared contexts used is to direct attention to PTS as physical and tangible technological solutions that pupils are expected to be able to identify and analyse, as well as to be able to design and control with programming, according to the Swedish syllabus for technology. Therefore, the prepared contexts in the empirical studies were constituted by the programming material BBC micro:bit and PTS from every-day life. Adawi et al. suggest that the use of prepared contexts increases the chances of obtaining a more varied picture of how pupils experience the phenomenon.

Collection of the empirical data

The thesis is based on two data collections. The first data collection consists of semi-structured interviews with 23 pupils aged 11-12, from two different schools. This form of interview is suitable because I, as a researcher, direct the interview based on predetermined questions, but there is also room for the pupil to control the interview to some extent. This means that, based on what the pupil answers, I can ask follow-up questions to get an in-depth understanding of the pupil's answers. Prior to the semi-structured interviews, an interview guide (Appendix 1) was produced, which had been pilot tested on a number of pupils and then revised. The interviews were held individually with the pupils during school hours in a room next to their regular classroom. All interviews were recorded. In the interviews, prepared contexts were used with the aim of framing the interview questions in a way that directs pupils' attention to the phenomenon, in a context that is familiar to the pupils. I have used different objects that represent PTS that the pupils are expected to be familiar with, e.g. a TV remote control, a digital thermometer, a car key, and ready-made designs constructed from the programming material BBC micro:bit.

The second data collection consists of pupils' sketches, video recordings and interviews collected from a situation when pupils were working on designing a PTS with the BBC micro:bit. 8 pupils aged 10 (Grade 4), and 6 pupils aged 14 (Grade 8), participated on two different occasions. The pupils worked in pairs and were introduced to a technological problem (Appendix 5) by the researcher. The task was to design a burglar alarm that is controlled by programming with the aid of the BBC micro:bit material. The first part of the task was to discuss and sketch an idea for a PTS with paper and pen. The next step was to realise the idea of the PTS by using the BBC micro:bit and to use an iPad or computer to program the code. The pupils in Grade 4 used computers and the pupils in Grade 8 used iPads. The pupils' sketches were collected as data. The pairs of pupils were video recorded while working on the task, using a GoPro camera attached to the ceiling above each pair of pupils. A screen-recording program was used to record the activity on the screens when the pupils programmed the BBC micro:bit on the iPad. Unfortunately, it was not possible to do this on the computers due to limited access to that type of software on the pupils' computers. However, the activity on the computer screen was instead captured by the GoPro cameras. A microphone was also placed in front of each pair of pupils to capture what was being said while they were working on the task. As the pupils worked, predetermined questions were asked (see Appendix 3) in order to direct the pupils' focus to the PTS. After the pupils had completed the task, semi-structured interviews were held with each pair of pupils, based on questions in the interview guide (Appendix 3).

The analysis of data

The analysis of the empirical data was conducted in line with the phenomenographic approach. The data included in the analysis consists of transcribed interviews from Data Collection 1, and the transcribed video recordings, transcribed interviews and pupils' sketches from Data Collection 2. The interview materials and parts of the video material have been transcribed verbatim, where the transcriptions of the video material also include descriptions of pupils' actions in the process of designing the PTS. The analysis of actions in phenomenographic studies has been useful in previous studies (see e.g. Nyberg & Carlgren, 2015; Björkholm, 2015). Further, based on the empirical data, pupils' qualitatively different ways of experiencing the phenomenon have been analysed and described. In Paper 1 and Paper 2, the qualitatively different ways of experiencing the phenomenon have been arranged in hierarchical categories of increasing complexity, which are logically related to each other, and which together constitute the result (i.e. the outcome space) in each of the two papers, from which critical aspects can be identified. In Paper 3, the analysis directs attention to the sequential development of the design process, where the analysis is based on critical aspects of the two experienced phenomena that were previously identified in Paper 2. The aim is to investigate pupils' sequential discernment of critical aspects of the central phenomena in the process of solving a real-world task with the BBC micro:bit, and what effect the way of experiencing the phenomena has on how the process unfolds.

As described in the previous chapter, the phenomenographic analysis is based on identifying pupils' qualitatively different ways of experiencing phenomena. This is done by investigating the variations in ways of experiencing a phenomenon, and the critical differences between the ways of experiencing in terms of what parts of the phenomenon the pupils direct their focus of awareness towards. In this way, the critical aspects of the phenomenon can be identified. From the phenomenographic perspective on learning, learning means experiencing the phenomenon in a new way. More specifically, this means that the parts of the phenomenon, the relationships between the parts and how they relate to the whole phenomenon are distinguished in a new way. These parts are described as the structural aspects and referential aspects, which are closely intertwined and are present in the pupils' awareness simultaneously as the phenomenon is experienced (Marton & Booth, 1997). As part of the analytical work within Paper 1 and Paper 2, the structural and referential aspects are identified in relation to the categories within each outcome space. In this way, an overview is provided of what characterises the different ways of experiencing the phenomenon. Further, by investigating the differences between the categories in the outcome space, i.e. the critical differences in pupils' ways of experiencing the phenomenon, the critical aspects are identified. The critical aspects are what is necessary for the pupils to discern in order to reach a more complex way of experiencing the phenomenon. In the following, I will provide a more in-depth description of the analytical work in the individual papers.

The analytical work in Paper 1

In Paper 1, the empirical data, consisting of transcribed interviews from Data Collection 1, was analysed. The aim was to gain knowledge of pupils' qualitatively different ways of understanding PTS when analysing structure and function. Initially, all transcripts were read through repeatedly to get an overall picture of the content. From this reading, the pupils' approach to PTS seemed to differ, depending on which of the prepared contexts the pupils were discussing: the BBC micro:bit designs or the PTS in everyday life. Therefore, the analysis was divided into two parts based on the two contexts. The transcripts from parts of the interviews that related to each context were read repeatedly. After this, excerpts were selected that represented pupils' different ways of understanding PTS in the two contexts. These excerpts were interpreted and combined into different categories. The categories were analysed and then defined with respect to the structural and referential aspects, which represented the understanding within each category. Then the data was tested against the defined categories to adjust the definition of the categories. The pupils' different understandings constituted two different outcome spaces, i.e. two sets of categories: one related to experiencing BBC micro:bit constructions and one related to experiencing PTS in everyday life, where each included four different categories. Finally, the two outcome spaces were compared to find similarities and differences, and then integrated into a common outcome space.

The analytical work in Paper 2

In Paper 2, the transcribed video recordings, transcribed interviews and pupils' sketches from Data Collection 2 were analysed. The aim was to explore pupils' ways of experiencing the design and coding of a PTS using the BBC micro:bit, and to identify technological knowledge, in terms of critical aspects, that are needed in the process. The analysis started by analysing pupils' sketches. Based on the variation in the sketches, categories could be created. After that, the transcribed interviews were analysed. The transcribed data was read through several times to identify passages that represent differences in ways of experiencing the design and coding of the PTS. Excerpts were selected that represent the differences, and these were interpreted and grouped into categories based on their content. The next step was to watch the video recordings to identify sequences in the material that represent differences in ways of experiencing the design and coding of the PTS. The identified sequences were transcribed verbatim, along with descriptions of pupils' actions, and excerpts were then selected that were interpreted and grouped into categories based on their content. Hence, based on the different sources of data, the initial part of the analysis resulted in a set of preliminary categories which revealed that the pupils experience two intertwined phenomena during the design process: the dual nature of the PTS (i.e. structure and function of PTS) and the BBC micro:bit material. The next step was to analyse the two phenomena separately to gain knowledge of the ways pupils experienced each of them. Therefore, the preliminary categories based on the different sources of data were merged together into common categories based on their differences and similarities in relation to each phenomenon. This resulted in two separate outcome spaces, one for the dual nature of the PTS and one for the BBC micro:bit material. The next step was to further analyse these two preliminary outcome spaces and their categories of description in terms of the structural and referential aspects that characterise pupils' ways of experiencing the phenomena in each category. The categories within each outcome space were then tested on excerpts of data, and adjusted. By identifying the critical differences between the categories, the critical aspects within each outcome space could be identified. With respect to each category within the two outcome spaces, excerpts were selected that represent the way of experiencing the phenomenon. Finally, the two outcome spaces were explored in relation to each other as parts of the process of designing a PTS with the BBC micro:bit.

The analytical work in Paper 3

The analysis in Paper 3 took its point of departure from the results of Paper 2, with the previously identified critical aspects being used as an analytical framework. By returning to the same data (pupils' sketches and video recordings), the aim was to analyse the sequential development of the process based on pupils' discernment of the phenomena and their critical aspects, and what effect their way of experiencing the phenomena had on how the process unfolded. As the first step of the analysis, the video material from each pair of pupils was analysed and sequences were identified in which pupils expressed their way of experiencing the phenomena, both in actions and in words. The identified sequences were then transcribed verbatim along with descriptions of the pupils' actions. The transcribed video material was further analysed, along with the pupils' sketches, in three steps, in which the previously identified phenomena and their critical aspects from Paper 2 were used to frame and structure the analysis in a systematic way. The first step was to connect the identified sequences, in which pupils expressed their way of experiencing the phenomena, to sequential stages of the process i.e. the planning and sketching part where pupils analyse real-world conditions in relation to the dual nature of the PTS, and the part where they assemble and code the PTS in the BBC micro:bit context. Next, the analysis was directed towards pupils' discernment of critical aspects of the phenomena as expressed in their discussions and actions, in the sequential stages of the process, and whether the pupils recognised the meaning of the discerned critical aspects in relation to each other. Finally, the analysis was directed to the process as a whole and its sequential development, based on the effects that the way pupils experienced the phenomena had on how the process unfolded, i.e. whether the pupils were able to proceed in the process or not, and what direction the process took.

Reliability of the studies

In phenomenographic studies, the empirical data is based on individuals' different experiences of a phenomenon. These experiences are analysed and interpreted by the researcher, which in turn places demands on the reliability of the studies. The reliability in this context is based on the criteria described by Lincoln and Guba (1985) as: trustworthiness, credibility and transferability.

Trustworthiness

The pupils who participate in the studies contribute different ways of experiencing the phenomenon, based on their history and contextual factors. However, these factors become invisible in the processing of data in a phenomenographic study. Thus, the results, i.e. the categories of description, will only retain a decontextualised meaning and structure of the different ways of understanding the phenomenon, and the only thing left is the researcher's interpretation of empirical data (Marton & Booth, 1997). The results therefore depend to a large extent on the researcher's interpretation of the data. In phenomenography, the term trustworthiness is used to describe content-related validity regarding the researcher's familiarity with the investigated phenomenon (Collier-Reed et al., 2009). This requires knowledge of the phenomenon that is studied. A threat to trustworthiness occurs if the researcher is not fully familiar with the investigated phenomenon. For example, if the researcher lacks knowledge of the phenomenon, it is difficult to conduct semi-structured interviews, since these are based on questions and follow-up questions in relation to pupils' answers, which requires knowledge of the phenomenon. It will also be difficult to set up situations to investigate individuals' experiences if the researcher lacks knowledge of parts of the phenomenon, or lacks knowledge of the contexts in which these parts might appear. Hence, the researcher needs a broad knowledge of the phenomenon, both of its constituent parts and how it is represented in different contexts. This knowledge is necessary in order to be able to interpret the ways pupils experience the phenomenon, both in the collecting of data and in the analysis of pupils' ways of experiencing the phenomenon. My knowledge of the phenomenon PTS has been shaped through my own education and by becoming familiar with previous research with respect to PTS, as well as from my experience as a teacher of technology. The teaching experience also implies that I am used to communicating with pupils of the same age as the participants in the studies regarding PTS, which is an important aspect with respect to trustworthiness and the collecting of data.

Credibility

The selection of pupils and their suitability to participate and answer questions is an important part of the credibility of the studies in the thesis. The studies are based on two data collections where a prerequisite was that the pupils who participated had encountered the phenomenon PTS in teaching earlier, so that they would be familiar with the phenomenon and that they would be able to answer questions and work on tasks concerning the phenomenon. Another important issue concerning credibility is how the interviews and activities are designed with respect to their structure and content. Collier-Reed et al. (2009) suggest that there are important issues for the researcher to reflect upon in phenomenographic research in relation to credibility. They provide examples of questions to be reflected on: Are the interview questions appropriate in relation to the content? Are the interviews or activities conducted in a way that allows the pupils to feel free to respond or act in their own way? Are there any leading questions that could affect the pupils' answers? Can the pupils understand what phenomenon they are talking about? By conducting a pilot study, many of these questions can be answered. In the studies described here, a pilot study was conducted in relation to the design of the interview guides that were used. Further, by using prepared contexts in the form of different representations of PTS, the phenomenon could be framed, and thus it could be ensured that I, the researcher, and the pupil were experiencing and discussing the same phenomenon.

Transferability

In order for the results of the phenomenographic studies to be transferable to the rest of the research community, a review of the reliability needs to be made possible. It is important for information to be made available regarding how the data was collected, and how interviews and video recordings were conducted, and for this study this was done in articles, as well as at conferences and seminars. Another important way to make the data transferable is to give the research community the opportunity to become familiar with the data themselves, by presenting transcripts from the interviews and the video material. This is also an important way to ensure the trustworthiness of the results of phenomenographic studies. In order to increase transferability and trustworthiness, the data has been presented at seminars and conferences where other researchers have been given the opportunity to interpret the data in relation to the results. In this way, my interpretation of the data has been tested and validated.

The result of a phenomenographic study, i.e. the outcome space, is decontextualised during the research process because it only retains meaning and structure in relation to the different categories of description, based on the collective experiencing (Marton & Booth, 1997). However, as mentioned above, meaning and structure are based on the pupil's individual experience. So even though we claim that we are not interested in the pupils' individual understandings but in the collective understanding, we must in some way relate the results to the individuals because they are the basis for the research results. Furthermore, if we conducted the study in the same way in a different group of pupils, it would not necessarily yield the same set of categories. This may be considered as a limitation of phenomenographic studies regarding the possibility of generalising the results. However, a way to overcome this limitation is to provide insight into how the study has been conducted so that opportunities are given to analyse the aspects that underpin the study, such as context, pupils' prior knowledge, and the amount of previous teaching. Furthermore, by providing transcripts of data, the decontextualised results can be brought back to the individual's experience in a specific situation, including its contextual factors. The underpinning aspects may then be evaluated in relation to other contexts where the research outcome may be relevant. It is therefore important to give other researchers insight into how the study has been conducted as well as insight into the underpinning aspects of the study, such as contextual factors, since this provides the opportunity to analyse and evaluate the research results in relation to other contexts where they may be relevant.

The conclusion from the above is that the way of conducting phenomenographic studies, from the planning stage and the preparation of the studies, all the way to the results, is in many ways crucial for the reliability of the studies. By providing details and descriptions of the studies, and how they have been carried out, I have increased the possibility of assessing the reliability as well increasing the transferability to the research community.

Ethical considerations

The thesis has an empirical basis, constituted by investigations of pupils' relationship to PTS. This implies investigations of pupils' experiences of the phenomenon in situations involving analysing and designing PTS, i.e. where the pupils themselves are being studied. The collection of empirical data has therefore been carried out by interviewing and filming pupils in these situations, and also by collecting data such as pupils' sketches. In relation to this, ethical considerations have been made before, during, and after the collection of data, as well as in relation to the studies that have been carried out based on the data collections. This was due to the fact that the data collections include pupils aged 11-14 years. When designing and conducting collection of data as well as the studies, ethical rules have been applied and followed, in line with the Swedish Research Council's recommendations (Vetenskapsrådet, 2017), as presented below:

- The information requirement: Before the study begins, pupils and their guardians should be informed of the purpose of the study and that participation is voluntary (see Appendix 2 and Appendix 4).
- The consent requirement: Pupils have the right to decide whether they want to participate in the study and written consent should be obtained from their guardians (see Appendix 2 and Appendix 4).
- The confidentiality requirement: This requirement implies that everyone involved in the study must be guaranteed the greatest possible confidentiality. Pupils participating in interviews and video recordings must be anonymised so that they cannot be identified in the transcribed material or in pictures/videos.
- The utilisation requirement: The above materials should only be used in connection with this study and should be stored in a safe place to avoid unauthorised distribution.

In order to be able to carry out the studies, the consent of all concerned was required, such as pupils, parents, guardians, teachers and principals. Prior to each data collection, the consent of teachers and principals at the participating schools was first sought by sending information to them about the purpose of the studies, how data would be collected and in what way the pupils would participate. In relation to this, teachers and principals were also informed about confidentiality and self-determination regarding participation. After the teachers and principals decided to participate, a letter was sent together with a consent form to the pupils and their parents (Appendix 2 and Appendix 4). The letter contained information about the purpose and implementation of the study and in what way the pupils were expected to participate. The letter also contained information about confidentiality, self-determination regarding participation and the possibility of withdrawing from the study at any time, as well as how collected data would be handled and stored. At the times when the data was being collected, the pupils were again informed about the study and how it would be carried out. The pupils were also informed that they could withdraw from the study at any time.

Thus, the studies have been carried out in accordance with the Swedish Research Council's ethical principles for humanities and social science research, and in accordance with The General Data Protection Regulation (GDPR, 2016/679a). This implies that collected material such as pupils' sketches, the video recordings and audio-recordings, which are counted as personal data, have been handled with respect for the individual's integrity and stored in such a way that unauthorised persons cannot access them. Furthermore, the pupils who participate in the recordings have been anonymised in the reporting of the studies, where names have been changed to fictitious names in the texts that have been published or will be published. In Data Collection 2, video recording was used, which means that anonymisation is not as easy as in interviews alone. However, it was considered necessary to use video recording because the research focus is on pupils' experiences in the process of designing a PTS, and therefore pupils' experiences as expressed in both actions and words need to be documented and studied. However, it should be clarified that any images from the video recordings that will be used in the reports will be anonymised so that it will not be possible to identify the pupils.

Chapter 5: Results

This thesis comprises a review of the knowledge domain of programmed technological solutions (PTS) and three empirical studies in which the focus was on pupils' relationship to PTS. In this chapter, the results from the three studies, as presented in the three corresponding papers, are brought together in relation to the knowledge domain of PTS. Together these contribute to answering the overall research question: What key elements are important to address in teaching and learning technology in processes of analysing and designing PTS?

Critical aspects, contexts and systems thinking

The combined results from the individual papers show that there are certain aspects of PTS that are critical to discern in order to be able to experience PTS in a powerful way in processes of analysing and designing. However, the context of these processes, i.e. the BBC micro:bit material and the everyday objects, brings certain relevance structures to the situation that initially direct pupils' attention to more or less relevant aspects of PTS, which affects the way pupils experience PTS. When pupils approach the PTS, they seem to use systems thinking to different extents to discern present and appresented parts, as well as the complexity of the part-whole structure of PTS. Thus, the results indicate a relationship between the aspects of PTS that are critical to discern, the relevance structure brought to the situation by the contexts, and systems thinking as a strategy to be able to experience PTS in a powerful way, when teaching and learning technology in processes of analysing and designing PTS. In the following, these results will be presented and further described in three parts: aspects of PTS that are critical to discern in the processes, relevance structures provided by the contexts, and seeing the part-whole structure of PTS. In the final section, the results will be summarised with respect to the overall research question.

Aspects of PTS that are critical to discern in the processes

In phenomenography, learning is considered as a function of discerning the critical aspects of a phenomenon. Thus, the critical aspects of PTS can be considered as key elements to address in teaching and learning with respect to PTS. The aim in the phenomenographic studies in this thesis was to investigate the qualitatively different ways pupils experience PTS in the processes of analysing and designing PTS, and to identify critical aspects of PTS in the context of these processes. In Paper 1, the aim was to investigate pupils' different ways of understanding PTS when analysing the structure and function of PTS in the BBC micro:bit context and in an everyday life context. The results show that pupils approach PTS differently in these contexts. However, independent of context, the results also show that the aspects of PTS that are critical to discern in both contexts are: how the individual components work and what their function is in the PTS, the organisation of components, the logic in the code and how the code controls the components and the flow of information that determines the function of the PTS.

In Paper 2, the aim was to identify what technological knowledge pupils need in terms of critical aspects when designing a PTS with the BBC micro:bit material. The results show that pupils experience two intertwined phenomena during the process: the dual nature of PTS (i.e. the structural and functional nature of PTS) and the BBC micro:bit material itself. Further, the results from both Paper 2 and Paper 3 indicate that pupils' ability to achieve the PTS in the design process is dependent on the extent to which they are able to discern aspects of both phenomena and relate them to each other during the process. The aspects that are critical to discern concerning the dual nature of PTS are: the logic in the code in terms of feedback control, how the components work and how they can be organised, the interaction between the code and the components based on feedback control and how this generates a flow of information that controls the function of the PTS. The aspects that are critical to discern concerning the BBC micro:bit material are: what the blocks represent in terms of real-world conditions and in terms of programming concepts, the shape of the blocks as well as how the blocks are organised in the editor, the need for a control function in the code and how the code can be combined in terms of blocks to control the function of the PTS.

Table 1 provides a summary of the aspects that are critical to discern in the processes of analysing and designing PTS.

Table 1 Aspects that are critical to discern in processes of analysing and designing PTS

Analysing PTS (Paper 1)	**Designing PTS (Paper 2)**	
PTS Structure and function	PTS Structure and function	The BBC micro:bit material
The logic in the code and how it controls the components	The logic in the code – feedback control	What the blocks represent as real-world conditions and as programming concepts
How the components work and their function in the PTS	How components work	The shape of the blocks
The organisation of components	The organisation of components	The organisation in the editor
The interaction between the code and the components that generates a flow of information that determines the function of the PTS	The interaction between the code and the components that generates a flow of information that controls the function	The need for a control function in the code and how this can be combined in terms of blocks to control the PTS

(Developed from the results in Paper 1, Cederqvist 2020, and from the results in Paper 2, Cederqvist 2020)

From the table, the following key elements in terms of conceptual and procedural technological knowledge can be identified:

Knowledge related to the dual nature of PTS, i.e. the structure and function of PTS (based on the aspects that are critical to discern), which involves:

- Knowledge of feedback control
- Knowledge of components such as sensors, processors etc.
- Knowledge of how components can be organised to fulfil the function in PTS
- Systemic knowledge for understanding the interaction between the code and the components that generates the flow of information that controls the function.
- Knowledge of how to interpret and control a flow of information in PTS, i.e. knowledge of programming (including programming concepts)

Knowledge related to the programming material to be used to represent the PTS, as well as for producing the PTS in the process of designing, which is the BBC micro:bit material in this case (based on the aspects that are critical to discern), which involves:

- Knowledge of how the structural and functional nature of PTS is represented by blocks as real-world conditions
- Knowledge of programming concepts in order to control the flow of information in PTS and how these concepts are represented by blocks
- Knowledge of how to use the programming material in terms of its structure and function, such as interpreting the shape of the blocks and how the editor is organised
- Knowledge of how to produce code by combining blocks into a control function, e.g. feedback control

The results show that there is a complex of critical aspects that are necessary to discern with respect to PTS as they appear in the processes of analysing and designing. Further, the results show that pupils' different ways of experiencing PTS are based on the extent to which they are able to discern the critical aspects of PTS in the different contexts. Therefore, in the following section, the ways pupils experience critical aspects are related to the relevance structures brought to the situations by the contexts in the processes.

Relevance structures provided by the contexts

The results from the individual papers show that the context in which PTS appear affects pupils' way of experiencing PTS. That means that the contexts of the processes of analysing and designing, where different representations such as the programming material BBC micro:bit or other objects are used, provide certain relevance structures that indicate a certain way to experience PTS. In this section, the contexts in the papers will be presented and put in relation to the relevance structures in the situations as experienced by the pupils.

The contexts in the process of analysing PTS

In Paper 1, pupils were analysing the structure and function of PTS, both in a BBC micro:bit construction as a teaching material representing PTS, and in PTS in everyday life such as a TV remote control, a thermometer, a car key or PTS of their own suggestion. The results show that pupils approach PTS differently in the two contexts (Figure 4).

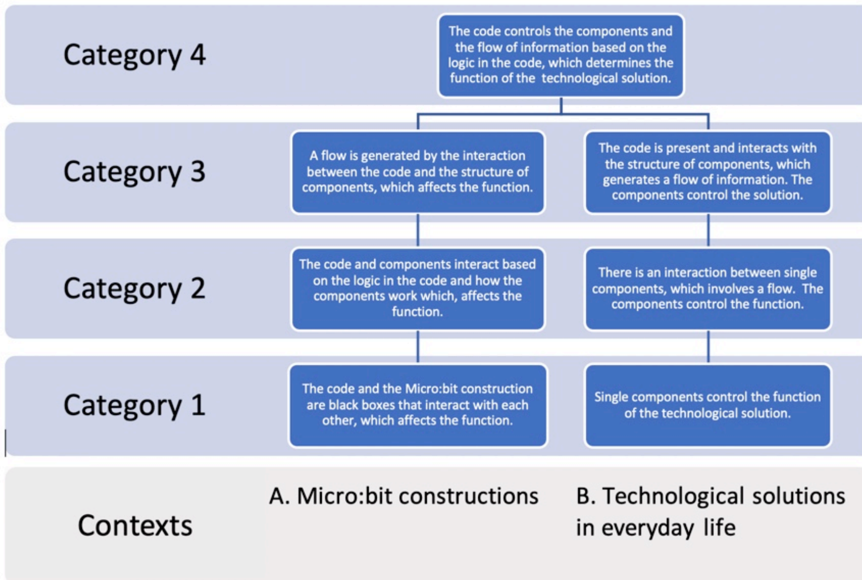

Figure 4 Pupils approach PTS differently in the context of BBC micro:bit constructions and in the context of PTS in everyday life

(Fig. 4, Paper 1, Cederqvist, 2020. CC BY 4.0.)

Furthermore, the results show that pupils' ways of understanding PTS when analysing structure and function are based on what critical aspects they are able to discern in the two contexts. When pupils are experiencing a BBC micro:bit construction, they initially approach it as a device with a function where the components and the logic in the code are "black boxes". The focus and awareness are on the interaction between the "black boxes" and what it may result in. The excerpt below (from Paper 1, Cederqvist, 2020), which represents Category 1A, shows how the pupil treats the code and components as "black boxes" that interact as parts of the whole device, which affects the function. It seems that the pupil has not yet discerned the logic in the code, nor how the components work, even if these parts may be considered as prominent and present in the context of the BBC micro:bit construction.

> Interviewer: No, but if we look at this code and these components that are here, do you think that you could describe for me how they work together?
> [...]

> Pupil 23: So there is a program here that somehow tells that one [the micro:bit] what to do and then that program is sent through the cable here to this [the micro:bit] and then what's written in there, that program is somehow made to work with that device. So it's sent to that one and then it does that...so the signal is sent, the program, then it's activated or whatever you want then, depending on what the program looks like it's activated and does what you have programmed it for.

However, according to the outcome space (Figure 4), there are pupils who in the same context are able to discern parts that can be considered as both present and appresented. In Categories 2 and 3, it can be seen that more and more critical aspects are discerned and finally in Category 4, all critical aspects are discerned, which means a more complex and powerful understanding. The excerpt below (from Paper 1, Cederqvist, 2020), which represents Category 4, shows how the pupil describes the interaction between the logic in the code and the components and how it generates a flow of information that make the PTS function.

> Pupil 6: [...] you've programmed that if it gets bright, that's set to start, well it's always running, but then it understands that it has to make the speaker play music and then it has to send [a signal] to the speaker that it should play that particular melody[...] it receives a lot of info and then it takes that and sends it on.
>
> […]
>
> Pupil 6: […] there is always something that has to send a signal if anything is going to happen.

In the context where the pupils are experiencing PTS from everyday life, such as a car key, a thermometer, a TV remote control or traffic lights, they approach PTS differently from PTS in the BBC micro:bit context. Initially, their focus and awareness are on parts that are prominent and present, such as single components, and how these control the function of the PTS directly. In the excerpt below that represents Category 1B (from Paper 1, Cederqvist, 2020), the pupil identifies and approaches the traffic light as a PTS based on a single component, a button that controls the function, i.e. when you push the button that is directly controlling the output, a change in colour occurs.

> Pupil 14: They are controlled like from an office, so it should go like this that now you change the colour type, and then it will be like that [...]
>
> Interviewer: Mm, and how does a traffic light know when it is going to change colour?
>
> [...]
>
> Pupil 14: A button. And then it will be that when you press a button like this say if this button is pressed then it will change colour like from red to yellow to green.
>
> Interviewer: And then the programmed [part] in this, how do you think it is then?
>
> Pupil 14: Then it's just that button and that it like goes from an office and that you don't like stand there and change it [the traffic light].

The excerpt indicates that the pupil has not yet discerned other components involved or the underlying process that generates the output. Pupils that express themselves in line with this category also do not discern that there is a code involved, even if they state that the object presented is a PTS. Further, in some cases, the focus on and awareness of single components as directly controlling the function of PTS cause the pupils to identify objects as programmed even if they are not. An example of this is shown in the excerpt below (from Paper 1, Cederqvist, 2020).

> Interviewer: […] do you think there are other things that are programmed?
>
> Pupil 12: Yes, I guess lamps probably are, it's kind of when you push the button, then the lamp lights up.
>
> Interviewer: Yes..?
>
> Pupil 12: They must be programmed yes.

However, in the same way as in the BBC micro:bit context, there are pupils who in the everyday life context are able to discern parts that can be considered as both present and appresented. In Categories 2 and 3, it can be seen that more and more critical aspects are discerned, such as the interaction between the components, the presence of a code and a flow of information. Finally, in

Category 4, pupils show a more complex and powerful understanding due to the fact that all critical aspects are discerned. The excerpt below (from Paper 1, Cederqvist, 2020), represents Category 4 in the everyday context. The pupil describes the buttons on the car key and how each button has a certain function connected to a code that includes instructions for what is going to happen when the button is pushed. Further, the interaction between the buttons and other components, such as the computer and a motor in the car, is described in terms of "messages" (i.e. information) being sent between them, which will determine the function in the PTS.

> Pupil 2: I think that there is maybe a sort of variable that has a name for each button, there are three buttons. And then we say the UNLOCK button that will unlock the car, there's a script for it that when the UNLOCK button is pushed on, ...signals are sent between or messages between them, the car and the key.
>
> ....
>
> Interviewer: Yes and then when the computer in the car gets information, it unlocks the car, but how does this function? Can the computer unlock doors in a car?
>
> Pupil 2: Well the computer is probably connected to these Makey Makey wires and there are certainly similar ones in the car that are connected to the computer and to a motor that has to...that the motor receives so the motor has two functions then, to close and to open, and when it receives this message or this wire sends OPEN, like this one [shows the car key] has sent to the computer in the car, then it goes to the motor that says OPEN and then it opens...

To summarise, when pupils are analysing structure and function in the context of the BBC micro:bit constructions, pupils may initially perceive the relevance structure as indicating that the PTS is to be experienced as a whole device. However, pupils experience the relevance structure in different ways based on their ability to discern parts, both present and appresented, such as how the components work or the flow of information. When pupils are analysing structure and function in the context of everyday life objects, pupils may initially perceive the relevance structure as indicating that the PTS is to be experienced in terms of parts that are present, such as single components, and what the PTS do, i.e. the function. However, pupils experience the relevance structure in different ways, depending on their ability to discern parts, both present and appresented, such as the code or other components that are not visible.

The results show that pupils' different ways of experiencing PTS are based on the extent to which they are able to discern the critical aspects of PTS in the different contexts. The outcome space (Figure 4) shows that in Category 4, all critical aspects of PTS are discerned in each context. Thus, Category 4 is the same for the two contexts and represents a more complex and powerful understanding, which allows pupils to transcend contextual details and move towards a general understanding of the structure and function of PTS. Further, the results of Paper 1 indicate that the way PTS are experienced in one context affects the experience of PTS in the other context. For example, the way of experiencing PTS in everyday life based on discerning single components, such as buttons that control the function directly, may be related to the use of programming materials such as the BBC micro:bit material, where buttons can be used as an input to generate an output, i.e. you push a button and something happens. Thus, if other critical aspects are not discerned in relation to the BBC micro:bit context, the way that pupils experience, e.g. the use of buttons as affecting the output directly, may serve as basis when transferring the understanding of PTS into the everyday context.

The relevance structures that the two contexts bring to the situation affect the way pupils experience the structure and function of PTS. This means that PTS are initially experienced differently depending on what aspects of PTS the contexts are able to bring the fore. If we consider the BBC micro:bit material as a representation that is used to highlight aspects of PTS to develop understanding of PTS in an everyday context, the results indicate the need for awareness of the ways pupils experience the relevance structure built up by the context of the BBC micro:bit material. Awareness is also necessary with regard to the differences and similarities between the relevance structures that the two contexts provide. In order for pupils to be able to transfer understanding between the contexts, and transcend the contextual details, which will allow them to generalise the understanding of PTS, they need to be able to recognise differences and similarities between the contexts .

The contexts in the process of designing PTS

Paper 2 and Paper 3 are based on data that was collected when pupils were presented with a technological problem in the real-world context (i.e. in the everyday context), where they were to design a burglar alarm using the BBC micro:bit material. The results show that in the process, the pupils are moving back and forth between the real-world context and the BBC micro:bit context (see Figure 5).

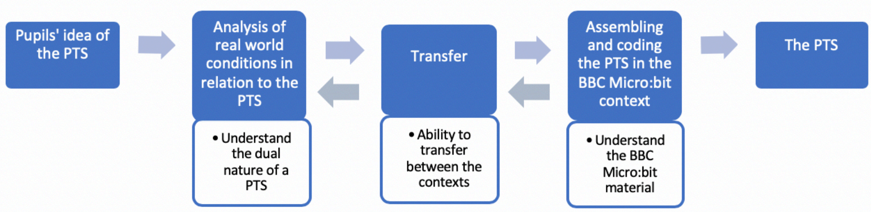

Figure 5 The process of designing a PTS and the relation between the two phenomena

(Fig. 7, Paper 2, Cederqvist, 2020. CC BY 4.0.)

The results also show that pupils' ability to accomplish the task of designing a PTS using the BBC micro:bit is dependent on to what extent they are able to discern critical aspects in both contexts during the process. In the process of designing the PTS, the initial step is to come up with an idea for a PTS based on the context in which the alarm would be used, i.e. the real-world context. An example of an idea was to place a light sensor in the cabinet to detect changes in light level that would activate the alarm when the cabinet door was opened. Thus, pupils initially needed to analyse the real-world conditions in relation to the structure and function of PTS as experienced in the real-world context. However, the results show that pupils approach the dual nature (i.e. structure and function of the PTS) in different ways in this context, based on what critical aspects they are able to discern (see Table 2).

Table 2 Pupils' ways of experiencing the dual nature of the PTS, as part of the process of designing the PTS

The dual nature of the PTS	**Structural aspects**		**Referential aspect**
Category	Logic	Organisation	Function
1. The black box approach	Discern fragmentarily what the code represents.	Discern components to use and how they can be connected.	Discern an interaction between the code and the components that affects the function in the PTS.
2. The white box approach	Discern what the code and its structure represent.	Discern components to use and how they can be organised.	Discern a flow that controls the function in the PTS generated by the interaction between the logic in the code and the structure of components.
3. The feedback-system approach	Discern what the code and its structure represent in terms of feedback control.	Discern components to use, how they can be organised, and how they work in the PTS.	Discern a flow of information that controls the function in the PTS with feedback generated by the interaction between the code and the components.

(Table 1, Paper 2, Cederqvist, 2020. CC BY 4.0.)

In the least powerful approach, the "black box" approach, pupils discern what components to use, and the interaction between the components and a code, which will affect the function. However, these are treated as "black boxes", which is probably the result of a vague understanding of how the components work and how to organise them, as well as what the code represents. Although all the pupils are exposed to the same context, there are pupils who are able to unpack the "black boxes". In other words, they are able to discern critical aspects such as what the code represents and how the components can be organised, and that the interaction between them generates a flow of information that controls the function. There are also pupils who in the same context are able to approach the structure and function of the PTS as a feedback system, i.e. they are able to discern the code and components as interacting based on feedback control. Thus, when pupils are initially analysing the real-world conditions with respect to the structure and function of the intended PTS, the technological problem in itself, i.e. to produce a burglar alarm, builds up a certain relevance structure that indicates a certain way to experience PTS. In other words, the staged technological problem as it is presented in the real-world context serves to present a whole in which pupils are challenged to distinguish the parts with respect to the structure and function of the PTS.

After the pupils have analysed the real-world conditions in relation to the structure and function of the PTS, the next step in the process is to transfer the structure and function into the BBC micro:bit context (see Figure 5). In other words, the intended PTS is implemented in the context of the BBC micro:bit material. However, the results show that the ability to implement the PTS in this context is based on the way pupils experience the BBC micro:bit material. Altogether, the results indicate three levels in pupils' ways of approaching the BBC micro:bit material (see Table 3).

Table 3 Pupils' ways of experiencing the BBC micro:bit material, as part of the process of designing the PTS

The BBC micro:bit material	**Structural aspects**		**Referential aspect**
Category	Logic	Organisation	Function
1. Novice user approach	Limited understanding of what the blocks represent.	Search randomly in the editor to find suitable blocks.	Do not discern the relation between the combination of blocks and the intended control function in the PTS.
2. Intermediate user approach	Discern what the blocks represent in terms of real-world conditions.	Discern the shape of the blocks but search randomly in the editor to find suitable blocks.	Discern the need for a control function in the code for controlling the function of the PTS but are not able to combine it in terms of blocks.
3. Proficient user approach	Discern what the blocks represent in terms of programming concepts.	Discern the shape of the blocks and how they are organised in the editor and navigate confidently to find suitable blocks.	Are able to combine a control function in terms of blocks to control the function of the PTS.

(Table 2, Paper 2, Cederqvist, 2020. CC BY 4.0.)

In the least powerful approach, the novice user approach, pupils do not discern what the blocks represent in relation to the analysed real-world conditions, and they are not able to interpret the shape of the blocks. As a result, they randomly snap together blocks and produce non-functional codes. However, the results show that at the other levels in pupils' ways of approaching the BBC micro:bit material, the pupils experience the material in a more powerful way. In the intermediate approach, pupils are able to discern what the blocks represent as real-world conditions and the need for a control function, as well as being able to interpret the shape of the blocks, which is used to bring together blocks into a code. In the proficient user approach, they also discern what the blocks represents as programming concepts, and are able to navigate in the editor confidently to find the blocks, as well as being able to combine the blocks to control the function of the PTS.

The results from Paper 2 and from Paper 3 show that many pupils have difficulties using the BBC micro:bit material to accomplish their intended idea for PTS. The results indicate that these difficulties are based on the fact that pupils are not experiencing the BBC micro:bit material in a powerful way. When pupils are transferring their idea of a PTS from the real-world context into the BBC micro:bit context, the BBC micro:bit material in itself builds up a certain relevance structure. In other words, the BBC micro:bit material also serves to present a whole in which pupils are challenged to distinguish the parts with respect to how they represent the structure and function of PTS. However, the results show that the relevance structure brought to the situation in the context of the BBC micro:bit material presents challenges when pupils are to distinguish the parts on their own. In Paper 3, which takes its point of departure from the results of Paper 2, the aim was to investigate pupils' sequential discernment of critical aspects of the dual nature of PTS and of the BBC micro:bit material, in the process of designing a burglar alarm with a BBC micro:bit, and also to investigate what effect the way of experiencing the phenomena has on how the process unfolds. The results show that several pupils tend to go off-track in the process when they are to move between the real-world context and the BBC micro:bit context, i.e. when they are to transfer their understanding of analysed conditions in the real-world context in relation to the dual nature of the PTS, to the BBC micro:bit context. The movement involves challenges, either because they are not able to discern the critical aspects of the BBC micro:bit material, or because they are not able to connect these aspects to aspects of the dual nature of PTS, which affect the process of moving towards the intended PTS.

To summarise, Paper 2 and Paper 3 show that solving a real-world problem by designing a PTS with the BBC micro:bit involves a process of transferring the experienced structure and function (the dual nature) of the PTS from the real-world context into the BBC micro:bit context. Thus, the relevance structures brought to the situation both by the problem to be solved in terms of a PTS in the real-world context, and by the context of the BBC micro:bit material, affect the way pupils experience PTS in the process of designing the PTS. Pupils' ability to accomplish the task of designing and coding PTS depends on first being able to discern critical aspects of the structure and function of the intended PTS as connected to the analysed real-world conditions regarding the problem to be solved. In other words, to be able to move forward in the process, the pupils need enough cohesion and detail with regard to the dual nature of the PTS, in order to have anything substantial to implement in the BBC micro:bit context. However, in order to implement the dual nature of PTS in the BBC micro:bit context, the pupils also need to be able to discern critical aspects of the BBC micro:bit context. This implies making a fit between aspects of the dual nature of PTS and aspects of the BBC micro:bit material. Therefore, pupils need to discern the part-whole structure of each phenomenon as provided by the relevance structures of the contexts, as well as make a fit between the part-whole structures, in terms of how they are related to each other in the process. According to the critical aspects identified in Paper 2, this involves knowledge of what components to use based on knowledge of how they work, as well as knowledge of how to organise the components in relation to a code based on feedback control. This knowledge is interrelated with knowledge of how to combine blocks into a code as a conditional statement. This implies knowing what the blocks represent in terms of real-world conditions, and in terms of programming concepts, as well as knowing how to interpret the shapes of the blocks, and where to find them in the editor. Thus, in order to be able to move between the contexts and make a fit between the part-whole structures in the process, pupils need to be able to recognise differences and similarities between the contexts, and be able to connect aspects of the dual nature of PTS as experienced in the real-world context, to aspects of the BBC micro:bit context.

Transcending the contexts

What becomes evident from the results of the papers is that in order to be able to transfer understanding of PTS between contexts, pupils need to discern the critical aspects of PTS in the previous context since this allows them to experience PTS in a powerful way in the other context. As the results from Paper 1 indicate, if pupils are not able to discern the critical aspects of PTS in the BBC micro:bit context, there are difficulties with transferring understanding of PTS into the context of PTS in everyday life. Further, as the results from Paper 2 and Paper 3 show, if when designing PTS, pupils are not able to discern critical aspects with respect to the structure and function of PTS in relation to analysed conditions in the real-world context, they have difficulties in moving forward into the BBC micro:bit context. In Table 4, the critical aspects of PTS are revisited. The table shows what aspects are necessary to discern in the processes of analysing and designing, in order to experience PTS in a more powerful way, with regard to the everyday context (real-world context) and to the BBC micro:bit context.

Table 4 Critical aspects for experiencing PTS in a powerful way in the processes of analysing and designing with respect to the everyday context and to the BBC micro:bit context

Analysing PTS	**Designing PTS**	
BBC micro:bit context – Everyday context	Everyday context	BBC micro:bit context
The logic in the code and how it controls the components	The logic in the code – feedback control	What the blocks represent as real-world conditions and as programming concepts
How the components work and their function in the PTS	How components work	The shape of the blocks
The organisation of components	The organisation of components	The organisation in the editor
The interaction between the code and the components that generates a flow of information that determines the function of the PTS	The interaction between the code and the components that generates a flow of information that controls the function	The need for a control function in the code and how this can be combined in terms of blocks to control the PTS

(Developed from the results in Paper 1, Cederqvist 2020, and from the results in Paper 2, Cederqvist 2020)

Being able to analyse an existing PTS, including BBC micro:bit constructions and everyday solutions, implies being able to discern critical aspects such as the logic in the code, how the components work and function in the PTS, how the components are organised, and how the code and the components interact to generate a flow of information that determines the function of the PTS. Thus, the pupils need to be able to discern the critical aspects in any of the contexts, in order to be able to transcend the contextual details, which will allow them to generalise their understanding of PTS. However, in order to be able to generalise their understanding of PTS and transfer it into new contexts, pupils need to discern critical aspects of PTS in different but connected contexts. In the process of designing PTS with the BBC micro:bit, the pupils initially experience the structure and function of PTS as part of the real-world context, i.e. as part of the everyday life context. The experienced structure and function are analysed and then transferred into the BBC micro:bit context where the PTS is to be assembled and coded. To be able to produce the PTS, the pupils need to make a fit between discerned aspects of the dual nature of PTS and discerned aspects of the BBC micro:bit material which represent the PTS, e.g. what the blocks represent in terms of real-world conditions and how to combine them into feedback control. In order to do this, they need to be able to see the differences and similarities between the different but interrelated contexts. Thus, technology teaching that aims to develop pupils' ability to analyse PTS may be preceded by activities that include the process of designing PTS. This means that pupils should first develop an ability to discern aspects of PTS in relation to changing contexts, and an opportunity for this is provided during the process of designing and coding a PTS for solving a real-world task. This may help them to conceptualise technological concepts and processes with regard to PTS, as this may be experienced in both a real-world context and in the context of a programming material. However, this implies that in these activities, the real-world context and the context of the programming material should be appreciated in order to see their interrelations.

To summarise, the results from the three papers show that pupils' way of experiencing PTS is dependent on contextual factors in the processes of analysing and designing. In other words, the contexts bring certain relevance structures to the situation which direct attention to certain aspects of PTS. Thus, aspects of PTS appear as more or less relevant for pupils, dependent on how PTS are represented in the processes by objects, the programming material or a staged technological problem. Accordingly, pupils' ability to discern critical aspects of PTS is dependent on the relevance structure brought to the situation, where the pupils derive meaning and structure from the way PTS appear in terms of experienced part-whole structures. Further, the more critical aspects that are discerned and understood in one context, the more potential this provides to understand PTS in a more powerful way in a different but connected context. However, to be able to transcend the contextual factors and to generalise the experienced part-whole structure of PTS from the different contexts, pupils need to be able to see the differences and similarities between the experienced part-whole structures of the contexts.

Therefore, as part of teaching and learning technology with respect to PTS in processes of analysing and designing, it is important to direct attention to the relevance structures brought to the situation by the context, i.e. by a programming material or everyday objects representing PTS. This implies appreciating the context of the programming material and the real-world context in relation to the dual nature of PTS, which involves being aware of:

- Aspects of the programming material in relation to the real-world context in terms of aspects of the dual nature of the PTS e.g. blocks as representing real-world conditions in relation to structural and functional aspects of PTS, or blocks as representing programming concepts in relation to the control function in PTS.
- Similarities and differences between PTS in the context of a programming material and in the context of everyday life (in order to be able to transfer understanding between contexts, and to be able to transcend contexts and move towards a general understanding of PTS).

Seeing the part-whole structure of PTS

The results from the papers show that for pupils to be able to transcend contextual factors and to experience PTS in a powerful way, pupils need to be able to see the part-whole structure of PTS in the different contexts, as well as being able to see the differences and similarities between them.

The results indicate that when pupils are presented with PTS in the different contexts, PTS are initially experienced as several undifferentiated wholes, of which the pupils are challenged to distinguish the parts. This means that PTS in everyday contexts do not appear in a similar way to how PTS appear in the context of a programming material such as the BBC micro:bit material. According to the results, pupils derive their understanding of PTS from parts of the contexts, which indicate a certain way to experience the PTS as a whole. In other words, pupils experience a situation as a whole in which the PTS is one part, where it appears with more or less relevance based on what parts are "seeable". However, the results show that if the undifferentiated whole in each of the contexts does not become differentiated, and the critical aspects are not discerned, it becomes difficult for pupils to move forward in the processes, both in terms of accomplishing the tasks and in terms of experiencing PTS as a relationship between parts and wholes. Paper 3 provides insights into pupils' way of sequentially discerning aspects of the dual nature of PTS, and aspects of the BBC micro:bit material during the process of designing a PTS with the BBC micro:bit. The two detailed examples in Paper 3 show that the contextual factors in the situation, i.e. factors related to the real-world problem to be solved and the BBC micro:bit material, are able to bring certain aspects to the fore concerning the structure and function of PTS. In this sense, the process can be considered as a representation of PTS, which is initially experienced as two undifferentiated wholes, i.e. the dual nature of PTS and the BBC micro:bit material, which pupils gradually learn to differentiate. The more critical aspects that are discerned of each of the wholes, the more differentiated and integrated the wholes becomes, and finally there is enough cohesion and detail to produce the intended PTS.

However, the results from Paper 3 show that not being able to discern the critical aspects and recognise their meaning in relation to each other, affect how the process unfolds. In the examples, the pupils are not able to discern some of the critical aspects or recognise their meaning in relation to other critical aspects, and they need scaffolding in order proceed in the process. This indicates that even though the contextual factors in the situation, i.e. the real-world problem as well as the BBC micro:bit material, may bring certain aspects of PTS to the fore, there are pupils who are not able to discern them or connect them to the dual nature of their intended PTS. On the other hand, there are pupils who are able to do this in the same situation, in the same context. This variation can also be seen in the results from Paper 1 and Paper 2. Thus, there are differences in pupils' ways of approaching the part-whole structure of PTS. The question is: What facilitates pupils' way of seeing the part-whole relationship in a more powerful way? According to the results from the three papers, there is one common element found: systems thinking, i.e. pupils are approaching PTS by using systems thinking.

The results from Paper 1 show that when pupils are analysing the BBC micro:bit constructions, they approach PTS by using systems thinking. Initially, pupils use a "black boxing" strategy since they are not able to discern aspects such as the logic in the code or the structure of components. Even if the strategy does not allow them to understand PTS in a more powerful way, the strategy helps them to experience the function of PTS. When they are analysing PTS in everyday contexts, they use a more user-driven approach based on their own experience of the PTS from, for example, single components such as buttons and how they affect the function. However, the more pupils are able to see the parts and how they interact, as well as the relation between the parts and the

PTS as a whole, the more powerful their way of experiencing the PTS in both contexts. This can be seen in Category 4 in the common outcome space (see Figure 4), which indicates a level of systems thinking where pupils are able to describe in detail the interaction between the code and the structure of components, which generates a flow of information that controls the function of the PTS.

In Paper 2, the results show that the different ways pupils approach the structure and function of PTS may be related to different levels of systems thinking (see Table 2). Initially they are "black boxing" the structural parts of the PTS, i.e. the code and the organisation of components, but they are able to discern the interaction between these "black boxed" parts and that this interaction affects the function. However, the more black boxes that are unpacked, the more powerful the way of experiencing both the structure and the function of the PTS becomes. This can be seen in Table 2 in the feedback system approach, where pupils are able to describe the purpose of using specific components, and how these can be organised, as well as how these interact based on a code in terms of feedback control to generate a flow of information that controls the function in the PTS. Thus, the results indicate that the level of systems thinking adopted may affect pupils' ability to move between the structural and functional aspects of PTS. Systems thinking is also considered to facilitate the movement between PTS as represented in the real-world context and PTS as represented in the BBC micro:bit context, since a thorough understanding of the structural and functional parts of PTS both as experienced in the real-world context, and in the BBC micro:bit context, facilitates the movements between the contexts.

With regard to PTS as part of different contexts in processes of analysing and designing, PTS are initially experienced as undifferentiated wholes of which the pupils are challenged to distinguish the parts. The results suggests that the level of systems thinking adopted by the pupils may help them to see the part-whole structure of PTS, which is based on both present and appresented parts. Further, when seeing the part-whole structure of PTS in different but connected contexts such as the BBC micro:bit context and the everyday context, pupils may, based on seeing the experienced PTS from a systems thinking perspective, compare the part-whole structures with each other to discern differences and similarities between parts and parts, and between whole and whole. In this way, systems thinking may help pupils to transcend the contexts towards a general understanding of PTS.

Consequently, the results suggest that systems thinking is a key element to address in order for pupils to be able to move forward and learn in processes of analysing and designing PTS, both in terms of experiencing PTS as a relationship between parts and wholes, and in terms of accomplishing the tasks. This involves understanding the parts of the PTS, understanding how the parts interact, and understanding the PTS as a whole, i.e. experiencing PTS as a technological system, which may help pupils to see the part-whole structure of PTS in a more powerful way.

Summary of the results

From a technology education perspective, the combined results from the three empirical studies as presented in the three papers, have been brought together with the knowledge domain of PTS to identify key elements that are important to address in teaching and learning technology in the processes of analysing and designing PTS. The identified key elements are:

1. Knowledge related to the dual nature of PTS, i.e. the structure and function of PTS (based on the aspects that are critical to discern), which involves:
    - Knowledge of feedback control
    - Knowledge of components such as sensors, processors etc.
    - Knowledge of how components can be organised to fulfil the function in PTS
    - Systemic knowledge for understanding the interaction between the code and the components that generates the flow of information that controls the function.
    - Knowledge of how to interpret and control a flow of information in PTS, i.e. knowledge of programming (including programming concepts)

2. Knowledge related to the programming material to be used to represent PTS as well as for producing the PTS in the process of designing, which is the BBC micro:bit material in this case (based on the aspects that are critical to discern), which involves:
    - Knowledge of how the structural and functional nature of PTS is represented by blocks as real-world conditions
    - Knowledge of programming concepts in order to control the flow of information in PTS and how these are represented by blocks

- Knowledge of how to use the programming material in terms of its structure and function, such as interpreting the shape of the blocks and how the editor is organised
- Knowledge of how to produce code by combining blocks into a control function, e.g. feedback control

3. Contextual appreciation, i.e. awareness of the relevance structure brought to a situation by different contexts used in the processes such as programming materials and other objects representing PTS. This means appreciating both the context of the programming material and the real-world context, in relation to the dual nature of PTS, which involves being aware of:
   - Aspects of the programming material in relation to the real-world context in terms of aspects of the dual nature of the PTS e.g. blocks as representing real-world conditions in relation to structural and functional aspects of PTS, or blocks as representing programming concepts in relation to the control function in PTS.
   - Similarities and differences between PTS in the context of a programming material and in the context of everyday life (in order to be able to transfer understanding between contexts, and to be able to transcend contexts and move towards a general understanding of PTS).

4. Systems thinking (i.e. to experience PTS as a technological system) in order to help pupils experience the part-whole structure of PTS in a powerful way, and to help them transcend the contexts and move towards a general understanding of PTS. This involves:
   - Understanding the parts of the PTS and how the parts interact, in relation to the PTS as a whole.
   - Being able to see the part-whole structure of PTS in different contexts.
   - Being able to compare PTS in different contexts, and see differences and similarities between parts and parts, and between whole and whole.

Chapter 6: Discussion

The overall aim in this thesis is to contribute to research on teaching and learning technology with respect to PTS. The focus has been on what technological knowledge is important for pupils to learn in relation to the knowledge domain of PTS, and in relation to the empirically investigated relationship between pupils and PTS as part of processes of analysing and designing PTS. The results indicate four main areas to direct attention to: knowledge related to the dual nature of PTS, knowledge related to the programming material that is used to contextualise PTS in the processes, awareness of the relevance structure brought to the situation by the context in the processes, i.e. contextual appreciation, and the use of systems thinking in order to facilitate discernment of the part-whole structure of PTS. In this chapter, the results will be discussed in relation to previous research with regard to what new insights the results contribute and what implications the results have for theory and practice, as well as limitations and strengths of the results, and suggestions for future research.

Contribution to technology education

The aim of this thesis is, from a technology education perspective, to identify key elements of teaching and learning technology with respect to programmed technological solutions (PTS). The results are both derived from the knowledge domain of PTS and from three empirical studies that investigate pupils' ways of experiencing PTS. This implies that the overall research question has been answered by taking into account two perspectives on what technological knowledge may be important for pupils to learn. This could be seen as a contradiction, but if we return to the didactical tetrahedron (Figure 1), which shows the complexity of relational aspects in teaching and learning situations, we can understand that it is necessary to combine two perspectives in order to provide pertinent technology teaching. In other words, the knowledge domain of PTS in terms of technological literacy sets the framework for what elements are important for pupils to learn, and the phenomenographic studies provide precision regarding what to address in order for pupils to learn. In this way, the thesis contributes knowledge that has implications for teaching and learning about PTS in technology education. In the following, this knowledge contribution will be discussed in relation to precision regarding what is to be learned, appreciation of the context, and using systems thinking as a way to approach PTS.

Precision regarding what is to be learned

In Sweden, as well as in other countries, programming and PTS have been implemented as part of technology education. Pupils are expected to develop knowledge of concepts and processes to understand how PTS work and are controlled by programming. As a way to contextualise this content in teaching, it has become common to let pupils take part in programming activities where they design their own PTS and control them with programming using different programming materials. However, what pupils learn from these activities is sparsely explored, and many teachers are uncertain of what knowledge to address (Sentance & Csizmadia, 2017; Webb et al., 2017). Further, a recent study by Nouri et al. (2020) shows that Swedish teachers expect pupils to develop more general abilities such as problem-solving skills and collaborative skills when taking part in programming activities. However, the results from this thesis indicate that there are limitations in only expecting learning in terms of general skills, without directing attention to the specific technological knowledge involved in the programming activities. When pupils are designing PTS with a programming material such as the BBC micro:bit, they face phenomena such as the dual nature of PTS (i.e. structure and function) and the BBC micro:bit material, which represents structural and functional aspects of PTS. These two phenomena are closely intertwined in the process, and involve both conceptual and procedural knowledge that it is necessary to grasp, i.e. both phenomena and their critical aspects are considered as necessary to discern to be able to proceed in the process of producing the PTS, as well as to understand how PTS work and are controlled by programming. The necessity of discerning the critical aspects in order to understand PTS in terms of a part-whole structure (i.e. the structural and functional parts) became evident when pupils were to analyse PTS in different contexts, such as the BBC micro:bit context and the everyday life context (Paper 1). Although the pupils had previously taken part in several activities where they had designed PTS with different programming materials, the results show that they are not necessarily able to discern the part-whole structure of PTS, in either the BBC micro:bit constructions or the everyday objects. Based on the results, the conclusion drawn is that if pupils are not able to see the part-whole structure of PTS in the BBC micro:bit context, i.e. the programming material that is used to contextualise PTS, they simply do not have a sense of a part-whole structure to be transferred into the everyday context.

The results indicate that it cannot be taken for granted that pupils automatically learn how PTS work, and how they are controlled by programming, from activities where the pupils are designing and coding PTS, which is in line with the results from previous studies (see Ivarsson, 2003; Pea, 1983). However, what this thesis adds is in-depth knowledge of the phenomena that pupils are experiencing in the activities, from the pupils' perspective, and what these phenomena involve in terms of technological knowledge. This knowledge is related to aspects of the dual nature of PTS such as, for example, knowledge of feedback control, knowledge of components, and knowledge of the interaction between the code and the components that generates a flow of information. The results show that these aspects of PTS are critical for pupils to discern, in order to be able to proceed in the process of designing and coding PTS, and to understand how PTS work and are controlled by programming. Similar results have been pointed out by Mioduser et al. (1996) and Slangen et al. (2011). What this thesis further adds is that the pupils also need knowledge in relation to the programming material that is used to represent and produce PTS in the processes. The results show that pupils need knowledge of the BBC micro:bit material regarding what the blocks represent in terms of real-world conditions and as programming concepts, the shape of the blocks and how to find them in the editor, and how to combine blocks into a control function. Furthermore, pupils need to be able to connect this knowledge to the structural and functional aspects of PTS, in order to be able to produce the PTS, and learn how PTS work and are controlled by programming. De Vries (2005) suggests that there are several factors that are necessary to understand and to make a fit between in processes of analysing and designing that should be addressed in teaching. This thesis suggests that knowledge of the programming material together with knowledge of the dual nature of PTS are factors that pupils need to understand and be able to make a fit between in processes of analysing and designing PTS. In other words, knowledge in relation to each of the phenomena needs to be addressed in terms of the aspects that are identified as critical to discern, as well as what the meaning of these aspects are in relation to each other, in order for pupils to learn how PTS work and are controlled by programming.

In technology education, the use of practical activities where pupils analyse and design PTS using different programming materials has become a common way to contextualise content related to PTS and programming. However, the report from 2014 by the Swedish Schools Inspectorate [Skolinspektionen] on Swedish technology education suggests that among technology teachers, there is an unreflecting use of pre-made teaching materials when staging practical activities, and that teachers sometimes neglect to direct pupils' attention to the theoretical knowledge that underpins the practical activities. As a result, there is a risk that pupils do not perceive the characteristics of technology, and that their learning of technology is limited (Skolinspektionen, 2014). This highlights the importance of addressing the technological knowledge involved in practical activities such as analysing and designing PTS. Further, Skolinspektionen suggests that if there is a lack of precision regarding what is to be learned in these kinds of activities, this also leads to an uncertainty regarding what is assessed in relation to pupils' abilities. Thus, the knowledge involved needs to be formulated and addressed with precision in order for the activities to be fruitful in terms of learning technology.

This thesis directs attention to the knowledge involved in practical activities such as processes of analysing and designing PTS using a programming material. Based on the three empirical studies and the knowledge domain of PTS, the contribution of the thesis is to specify more precisely what this knowledge is. The thesis suggests that understanding programming concepts and the ability to produce code are important elements in the processes of analysing and designing PTS. However, there are more elements embedded in the activities that attention should be directed towards. These elements are related to knowledge of the structural and functional nature of PTS, and to knowledge of the programming material used in the activity. Other elements that are shown to be important are contextual appreciation and systems thinking. In the next two sections, I will further discuss these key elements in relation to discernment of the part-whole structure of PTS, and the ability to generalise and transfer understanding of PTS between different contexts.

Appreciation of the context

In some teaching situations, the use of teaching materials plays an important role for learning (Rezat & Sträßer, 2012). When teaching technology with respect to PTS, situations are staged by using different programming materials to contextualise technological concepts and processes in order to facilitate learning. However, few studies have investigated in what way learning is facilitated in the context of a programming material. A previous study by Ivarsson (2003) shows that in a programming activity, the programming material's visual and interactive features may support pupils to solve problems. On the other hand, the study shows that pupils do not necessarily learn the concepts that are embedded in the activity, which they are expected to take beyond the context of the activity. Similar results have been found in this thesis, and this indicates the necessity of directing attention to the relation between the pupils and the phenomenon as pupils are given access to it in the context of a programming material. The contexts used when investigating pupils' way of experiencing PTS in the processes of analysing and designing are similar to contexts used in teaching, i.e. the BBC micro:bit material and PTS in everyday life. Seen from a phenomenographic perspective on learning, these contexts are used to build certain relevance structures that may facilitate pupils' discernment of the part-whole structure of PTS. However, the results show that the part-whole structure of PTS is more or less discernible for pupils in the different contexts that are used in the processes, and this seems to depend on the relevance structure that each of the contexts provides. As a result, pupils' ways of experiencing PTS as part of the contexts may affect how the processes unfold. If the contexts present challenges for pupils with regard to discerning the part-whole structure of PTS, this means that there will also be challenges when pupils are to transfer their understanding from one context to another.

The results indicate that if pupils do not discern critical aspects of PTS in the presented contexts, it becomes difficult to transfer meaning and understanding between the contexts. Paper 1 indicates that if pupils are not able to discern critical aspects of PTS in the BBC micro:bit context, they have difficulties transferring understanding of PTS into the context of everyday life. Paper 2 and Paper 3 show that if pupils, when they are designing PTS, are not able to discern critical aspects of the dual nature of their intended PTS, they have difficulties proceeding in the process of producing the PTS in the BBC micro:bit context. Moreover, if pupils are not able to discern critical aspects of the BBC micro:bit, they have difficulties moving forward in the process to produce the PTS. Thus, the experienced part-whole structure, based on the aspects of PTS that are derived from the relevance structures provided by the contexts, affect pupils' ability to transfer understanding of PTS between the contexts. Accordingly, as previously concluded, if pupils are not able to see the part-whole structure of PTS in the BBC micro:bit context, they do not have a sense of a part-whole structure to transfer into the everyday context, and vice versa.

Thus, the thesis suggests that it is necessary for pupils to discern critical aspects of PTS as they are presented in the contexts, to be able to experience PTS in a powerful way. If pupils are not able to experience PTS in a powerful way in the presented contexts, the consequence is that they lack a cohesive and detailed sense of the part-whole structure of PTS to be transferred between the contexts. As a result, pupils will have difficulties moving between the contexts, and generalising their understanding of PTS. These findings are in line with what Marton (2006) suggests regarding the necessity of discerning critical aspects of a phenomenon in different but connected contexts, in order to be able to generalise and transfer understanding of a phenomenon into new contexts. Therefore, the programming materials and other objects representing PTS, used in teaching to develop a general understanding of the structural and functional nature of PTS, need to be considered and carefully chosen in relation to the relevance structures they provide. This is underpinned by the theoretical premises in the thesis, that learning is dependent on the relevance structure brought to a teaching and learning situation (Lo, 2012; Marton & Booth, 1997; Marton, 2015), in which contextual appreciation is necessary (Linder & Marshall, 2003).

Consequently, appreciation of the contexts is necessary for learning in the processes of analysing and designing PTS. The teacher needs to be aware of what aspects of PTS pupils are given access to when using programming materials and other objects representing PTS. Pang and Ki (2016) suggest that teachers need to be aware that their choice of context, and how the phenomenon appears as part of the context in terms of aspects attended to by the pupils, may either facilitate or constrain the pupils' ways of experiencing the phenomenon. According to the results in this thesis, pupils are sometimes constrained in their ways of experiencing PTS in the processes, due to the contexts. The most difficult part for pupils is to transfer their understanding of the structure and function of PTS into the BBC micro:bit context where they are to produce the code in terms of feedback control. This difficulty is indicated by the fact that pupils do not understand what the blocks represent as programming concepts or what the blocks represent in terms of real-world conditions, in relation to the structural and functional aspects of PTS. Similar semantic difficulties have been shown by Grover and Basu (2017). What this thesis adds is how the design process is affected by these difficulties.

The results of Paper 3 show that when some of the pupils do not discern what the blocks represent, neither as real-world conditions nor as programming concepts, in relation to the structural and functional aspects of their PTS, it becomes difficult for them to combine a code. Instead, the pupils go off-track in the process, which constrains them in moving forward in producing the PTS. Similar results have been found by Ginestié (2018), who suggests that in activities where pupils are using programming to control technological solutions, a large amount of cognitive focus is devoted to solving programming issues when pupils do not understand how to program. As a result, there is less focus on learning other technological knowledge involved. Therefore, a programming activity using a programming material should be staged with consideration of the material's contextual benefits as well as of its constraints. It cannot be taken for granted that pupils understand and interpret the material as expected, and in the worst case, the activity may constrain pupils in learning technology.

However, the results indicate that some of the pupils were able to use the contexts in a way that helped them to understand how to produce the PTS. These pupils were able to connect, for example, the shape of the blocks to how to combine a code, or connect what the blocks represent to analysed real-world conditions in relation to the dual nature of their PTS. This allowed them to transfer their understanding between the different contexts in the process of designing the PTS. According to Marton (2006), pupils use their understanding of a phenomenon based on critical aspects of the phenomenon discerned in previous contexts, in order to see the differences and similarities between different but connected contexts. As described earlier, the pupils who participated in the studies had previously encountered the BBC micro:bit material and other programming materials in the classroom, and the objects that were used to represent PTS in the everyday context were familiar to them. This implies that the pupils have been provided with opportunities to discern critical aspects of PTS in previous situations in similar contexts, which for some has provided the conditions for developing a more generalised understanding of

PTS. However, the variation in pupils' ways of experiencing PTS indicates that not all of them have discerned critical aspects of PTS in the contexts in which PTS have been experienced previously. The reason for this can only be speculated on, but the findings have correlations to the previously mentioned study by Ivarsson (2003). That study shows that pupils taking part in a programming activity are able to solve rather advanced problems with the support of the visual and interactive aspects of a programming material. However, the problem is that they do not develop an in-depth understanding of central concepts that are embedded in the activity, that can take them further, beyond the context of that specific activity. A trial-and-error strategy may help them to solve the problem, but the pupils do not discern the critical aspects. Similar results have been found by Pea (1983), who suggests that if pupils do not gain a deeper understanding of concepts in a programming activity, they have difficulties reusing them in another similar context. Accordingly, pupils can design PTS and solve technological problems with the help of the contextual benefits of the programming material, without discerning critical aspects of PTS. However, what pupils learn from the process of designing PTS in these situations is another story. Furthermore, applying the trial-and-error strategy in the process of analysing the structure and function of PTS is difficult, or more to the point, not useful.

Thus, the thesis suggests that programming materials and other objects representing PTS may both constrain and facilitate learning in the processes of analysing and designing PTS. The contextual benefits can help pupils to experience PTS in a powerful way. However, we cannot take for granted that pupils are able to discern the critical aspects of PTS as part of the contexts, on their own. They need guidance from the teacher to understand and interpret the part-whole structure of PTS in the contexts in the expected way. Otherwise, pupils may attend to irrelevant aspects which may take them off-track, which constrains them in proceeding in the process. As a result, the learning outcome in terms of technological knowledge may be poor.

Using systems thinking as a way to approach PTS

The results indicate that systems thinking may be an important key for understanding PTS. In processes of analysing and designing PTS, the pupils seem to recognise the meaning of critical aspects in relation to each other and to the whole phenomenon of PTS, by approaching PTS as a technological system. In other words, their way of recognising the meaning of the parts in relation to each other, and to the whole, can be related to a systems thinking approach based on the three overarching abilities suggested by Booth Sweeney and Sterman (2007), i.e. to understand the parts of the system, to understand how the parts interact and to understand the system as a whole. Further, the results indicate that when pupils see PTS from a systems thinking perspective in the different but connected contexts, they are given the opportunity to compare the experienced part-whole structures, and to discern differences and similarities between contexts. However, the level of systems thinking adopted varies between pupils. The reason for this is not investigated here, but what is more important is that the variation between pupils indicates the potential for developing pupils' systems thinking within these age groups. If pupils are given more training to develop systems thinking based on the three abilities suggested by Booth Sweeny and Sterman (2007), there may be more potential for them to see the part-whole relationship of PTS in different contexts.

When considering teaching and learning with respect to PTS based on technological literacy, systems thinking should be seen as key element for preventing the "black box syndrome". This means that systems thinking may facilitate pupils' understanding of what happens in between the input and output of PTS they use in everyday life, and as a result, pupils are also able to become more critical consumers of PTS. Accordingly, the thesis suggests, which has also been pointed out by Slangen et al. (2011), that in order for pupils to understand how PTS work and are controlled by programming, the pupils need to learn about the structural and functional relationships between the input, the code, and the output. In order to learn this, systems thinking is suggested as an important key that will facilitate pupils' understanding of these structural and functional relationships, both in the context of a programming material and in the context of everyday life. Systems thinking may also facilitate the transfer of understanding between the contexts, and help pupils to move towards a general understanding of PTS.

Implications for teaching and learning about PTS

This thesis looks at teaching and learning technology in processes of analysing and designing PTS. From the results, as well as from previous studies in the field (see Mioduser et al., 1996; Slangen et al., 2011), we can understand that in these processes, pupils have difficulties that are related to both structural and functional aspects of the PTS as such, and to how PTS can be controlled by programming. Furthermore, the results indicate that being able to control the PTS is preceded by being able to understand what is made possible to achieve when programming the PTS, i.e. to understand how to produce a code that interacts with components in the PTS to achieve a specific behaviour and function in the PTS. To this end, the pupils need to understand the PTS in terms of analysed real-world conditions to be embedded in the structure and function of the PTS, i.e. knowledge of the components to be used, knowledge of how the components may interact, and how these together with a code may achieve the expected function of the PTS. Furthermore, pupils need to be aware of ways to control PTS, either by open-loop control or closed-loop control, i.e. feedback control, and what this implies in terms of the structure and function of PTS, as well as how this can be achieved by producing code, e.g. conditionals. Therefore, in order to be able to control a PTS, pupils first need to understand the structure and function of the PTS that is to be controlled, in relation to the real-world conditions that underpin the PTS, and second, they need to have knowledge of how to control the PTS in terms of programming concepts and how to use the programming material to achieve the PTS. This implies that the teaching of technology in relation to PTS should take its point of departure in the dual nature of PTS, in order to develop understanding of the structural and functional parts. As suggested by this thesis, as well as by Slangen et al. (2011) and De Vries (2005), systems thinking may facilitate this understanding. Furthermore, De Vries suggests that systems thinking also facilitates the design process by making the movements between structural and functional aspects more explicit. As indicated in the results, systems thinking may help pupils to transfer the part-whole structure of PTS between different but connected contexts, when pupils are to compare and see differences and similarities between parts and parts, and between whole and whole. This can help pupils transcend the contextual details and move towards a generalised understanding of PTS.

When pupils are able to conceptualise the structure and function of PTS, they can more easily proceed in the process of learning how to control the PTS. However, according to this thesis, and also according to previous studies (Mioduser et al., 1996; Slangen et al., 2011), there needs to be an awareness that controlling the PTS with programming appears to be the most difficult part for pupils to grasp. Hence, in relation to the expected learning outcomes in terms of being able to control PTS with programming, and in relation to the time dedicated to technology education, the focus in teaching should be aligned with these factors. This implies letting pupils develop knowledge of the control of PTS in terms of programming concepts, in relation to PTS commonly expected to be achieved in tasks that are used in teaching for their age group. The tasks in the papers involved two BBC micro:bit designs, the name badge and the burglar alarm, which differ in the way they are controlled. The name badge uses open-loop control, which is easier for pupils to conceptualise. The burglar alarm, however, uses feedback control, which is much more difficult to conceptualise in terms of code. As suggested by Ivarsson (2003), we cannot take for granted that pupils easily learn the programming concepts involved. This thesis suggests that pupils require instruction regarding the programming concepts involved, which need to be addressed with regard to how they can be understood in relation to the structural and functional aspects of PTS as understood in a real-world context. In other words, if pupils are expected to design PTS based on feedback control, they need to learn what feedback control implies in terms of functional and structural aspects of PTS in the real-world context, and be able to put this in relation to, for example, a conditional statement.

In conclusion, the results of this thesis show that when teaching and learning technology in processes of analysing and designing, PTS should preferably be experienced in different but connected contexts. This allows pupils to learn to see the part-whole structure of PTS in different contexts, in order to be able to generalise their understanding of PTS. However, teachers need to be aware of how PTS are represented in terms of programming materials, objects and technological problems, and what relevance structures provide learners with access to critical aspects of PTS. Thus, teachers need to be aware of both what the critical aspects are, as well as their potential for being discerned in the different contexts. This thesis provides knowledge about what these critical aspects are, as well as how these are embedded in the contexts of the processes, or, as Fredlund et al. (2014) put it, the contexts have been "unpacked" in order to provide knowledge about what access pupils are given to critical aspects of the phenomenon the context represents. Furthermore, systems thinking is suggested as an important key for being able to experience the part-whole structure of PTS in the contexts in which they are presented, as well as for being able to transfer meaning and understanding between contexts, and to learn in the processes.

Theoretical and methodological contribution

The theoretical and methodological contributions of this thesis relate to both technology education and phenomenography. In the thesis, the phenomenographic studies add a second-order perspective on the technological knowledge that teachers are expected to address when teaching technology. In this way, the thesis shows that phenomenography can provide precision with regard to the content that it is necessary to address in order for pupils to learn technology. The thesis also shows that there is an explicit relationship between learning technology with regard to structural and functional aspects and the theoretical underpinnings of phenomenography based on understanding the part-whole structure of a phenomenon. Further, the thesis offers a methodological contribution to phenomenography in terms of studying pupils' ways of experiencing the same phenomenon in different but connected situations, where different contexts are used to represent the phenomenon. In the following, these theoretical and methodological contributions will be discussed.

Adding a second-order perspective on technological knowledge

In this thesis, I as a researcher identify and describe aspects of technological knowledge with respect to PTS that can be of importance for pupils to learn, based on the knowledge domain of PTS (a first-order perspective). In the empirical studies, I investigate the ways pupils experience PTS in technological processes and I identify critical aspects of PTS that are necessary to address in teaching to develop pupils' ability to understand PTS (a second-order perspective). Further, within the empirical studies, there are certain criteria in the phenomenographic research process that align the first-order perspective and the second-order perspective. When implementing a phenomenographic study, it is necessary to determine and delimit what a phenomenon is. The trustworthiness of the studies, which can be referred to as content-related validity, relates to the researcher's familiarity with the investigated phenomenon. This requires knowledge of the phenomenon to be studied that is necessary both when collecting data and when interpreting pupils' ways of experiencing. Further, the pupils' subjective experiences of the phenomenon, which contribute to the variation within the whole group at a collective level, are sorted out into internally related categories of description. However, the categories of description will ultimately retain only the meaning and structure of the different ways of understanding the phenomenon. The pupils' subjective experiences are not seen or heard in this form, and the only thing that is left is the researcher's interpretation of the empirical data (Marton & Booth, 1997). By analysing the critical differences between the categories, the critical aspects of PTS can be identified, which in this thesis are used as indicators of what technological knowledge is necessary to address, based on pupils' ways of experiencing PTS. In this way, the results from the phenomenographic studies can be seen as an important contribution to technology education, in the sense that they add a relational perspective on technological knowledge and what it means in terms of teaching and learning technological content, taking into account the complexity of relational aspects in teaching and learning situations, as visualised in the didactical tetrahedron, i.e. the relationships between the pupils, the specific content as derived from the knowledge domain, and the teaching material that provides a certain context.

The relationship between technology and phenomenography

This thesis shows an explicit and important relationship between teaching technology and the phenomenographic perspective on learning. Understanding the technology we meet in everyday life implies being able to understand the nature of technological solutions (De Vries, 2005). This comprises structural and functional aspects, which can be understood as structural parts that interact with each other to fulfil an intentional whole or meaning, i.e. a function. Thus, to be able to understand technological solutions, it is necessary to understand the parts, the relationships between the parts, and to understand this in relation to the function. This structural and functional nature of technology can be related to the premises of phenomenography and the part-whole structure of a phenomenon, which it is necessary to discern in order to understand a phenomenon in a powerful way. Ingerman et al. (2009) describe this as being able to discern critical aspects of a phenomenon and recognise their meaning in relation to each other and to the whole. Further, technological solutions appear in different contexts, and in different shapes, which challenges pupils to understand them, as well as challenging them to develop a more generalised understanding when perceiving the solutions as part of contexts. However, in technology, there is an interplay between what one may understand of a phenomenon in one context, and how one perceives it in another context. This means, in accordance with what Marton et al. (2004) suggest, that the context affects the discernment of the part-whole structure, from the way the whole relates to the context. For example, in the process of designing a PTS, pupils constitute meaning from parts in the context, both present and appresent. In order to be able to produce the PTS as well as to learn technology in the process, pupils need to experience PTS in a powerful way, i.e. to discern critical aspects of PTS. From a technology education perspective, this implies that pupils need to learn to see the part-whole structure of phenomena in the different contexts they might appear. It also implies learning to see parts that are both present and appresent. As previously concluded, systems thinking may help pupils to see these parts, i.e. to see PTS as a technological system. Based on the same premises as in phenomenography, systems thinking directs attention to the understanding of structural parts in relation to the understanding of functional parts, in order to be able to see the part-whole relationship. This thesis shows, as does previous research in relation to both technology education and phenomenography, that pupils initially approach a phenomenon as an undifferentiated whole, which they gradually learn to differentiate in terms of its structural and functional parts (see e.g., Marton, 2015; De Vries, 2005). This implies, both from a technology education perspective and from the phenomenographic perspective on learning, that teaching should initially direct attention to the structural parts in order to allow pupils to fully grasp the functional parts.

Methodological contribution to phenomenography

One of the main contributions of this study to phenomenography relates to pupils' ways of experiencing the same phenomenon in different but connected situations, where different contexts represent the phenomenon. The thesis shows that pupils experience the same critical aspects regarding the structural and functional nature of PTS, irrespective of whether the situation involves analysing PTS or designing PTS. This shows a methodological rigour in using phenomenography when investigating ways of experiencing a phenomenon as part of different but connected teaching situations. Further, the results show that discerning the substantive content of the situation in terms of a phenomenon and its critical aspects is a prerequisite for the transfer of knowledge between the situations. This implies the necessity of developing knowledge of PTS in terms of its critical aspects when designing PTS, which can then be transferred to situations involving analysing PTS, and vice versa.

Further, the thesis shows that phenomenographic analysis can be applied to different types of collected data to determine the ways of experiencing the same phenomenon in the different but connected situations. In other words, the semi-structured interviews, pupils' sketches, and video-recordings of pupils working on the task, which are collected and analysed in the thesis, overlap with each other and indicate commensurable results.

Another methodological contribution to phenomenography is the way of studying a phenomenon as part of the design process using a teaching material such as the BBC micro:bit (Paper 2 and Paper 3). By staging an activity where pupils are working in pairs to solve a technological problem, there is an opportunity to capture pupils' discussions and actions during the process, both from their sketches and from video and audio recordings. This, together with the interviews after the activity, provides in-depth knowledge of how PTS are experienced as part of the process. One of the important findings in the thesis resulting from conducting phenomenographic research in this way, is that the phenomenon to be investigated is experienced, or so to say, appears as two interrelated phenomena in the process of designing a PTS, i.e. the dual nature of PTS and the BBC micro:bit material in itself, which represents aspects of PTS. The methodological contribution relates to the way in which the phenomenon was revealed as part of the process, where pupils' discussions and actions were investigated when pupils were making sense of the phenomenon in the process. The collecting of several sources of data helps capture pupils' discernment of critical aspects and how they recognise the meaning of these in relation to other critical aspects, as well as to the whole process of designing the PTS. Therefore, this way of conducting a phenomenographic study may be useful in future studies that aim to investigate phenomena as part of processes.

Limitations and strengths of the thesis

A limitation of this thesis is that the empirical data is based on only a few groups of pupils, and that these groups were of different ages (10, 11, 12 and 14 years). However, the results show that there were no differences regarding the outcomes of the studies that can be related to the age difference. The explanation for this may be that teaching and learning regarding the content of PTS and programming was recently implemented in the Swedish curriculum into all grades at the same time. Another limitation of this thesis is that the collection of data only took place in relation to certain contexts: one programming material, the BBC micro:bit, and a few objects from everyday life that represent PTS. This, together with the premise that technological knowledge is to a great extent context bound, presents challenges in relation to drawing conclusions from the results on a general level. However, the contextual delimitations in this thesis could also be seen as a strength. The results show that the contextuality is of great importance when pupils initially experience PTS, i.e. contextual factors affect the experienced relevance structure in the situations. This implies that in order to be able to understand how pupils learn technology in these contexts, it is paramount to investigate pupils' experiences in the specific contexts. Moreover, since the contexts were chosen from those that are commonly used in teaching, the results provide knowledge that is useful in practice when using these contexts. Thus, when it comes to drawing conclusions on a general level, this thesis shows, despite its contextual limitations, or rather because of its contextual limitations, that for pupils to be able to generalise their understanding of PTS, they need to learn to transcend contextual details. In other words, pupils need to experience the part-whole structure of PTS in different contexts in which they learn to discern parts of PTS in order to be able to compare differences and similarities between the contexts, and in this way, they become able to transcend the contextual details. Thus, the empirical studies make an important contribution to in-depth knowledge of what to learn, and how this may be learned, in the specific contexts. The strength of this thesis is that its findings are based on both the empirically investigated relationship between pupils and PTS, and the important elements that have been identified within the knowledge domain of PTS. As a result, the thesis can contribute answers to the question of what technological knowledge is of importance to address for pupils to learn technology with regard to PTS, in processes of analysing and designing PTS. However, the outcome of the thesis is only descriptive in this sense. The next step would be to make use of this contribution by applying it in technology education.

Suggestions for future research

Returning to the question of why to teach and learn technology with respect to PTS, the answer from a technology education perspective is: to develop pupils' technological literacy in order to enable them to understand, manage, use and evaluate the technology they meet in everyday life. However, the thesis only directs attention to certain parts of this, i.e. the processes and knowledge hidden behind PTS. Axell (2019) suggests that pupils also need to understand the technology in relation to the context of humans and society. Thus, the suggestion for future research is to direct attention to technological literacy and the ability to critically analyse and evaluate digital technology. This implies focusing on teaching and learning with respect to digital technology in terms of the possibilities and challenges it presents regarding sustainable development, and the consequences digital technology has for humans, society and the environment.

Chapter 7: Conclusion

Today we are to a great extent dependent on digital technology and the PTS that surround us in everyday life. However, ironically enough, it is common that we scarcely understand the technology we use, that we are only interested in the input and output and that what happens in-between is not of relevance (Dakers & De Vries, 2019). In order to prevent this "black box syndrome", the delivery of technology education has become even more important than ever. The implementation of programming as part of technology education came with the expectation of developing pupils' knowledge of how PTS work and are controlled by programming, which from a broader perspective would facilitate understanding of digital technology in general.

What this thesis concludes is that although programming is an important element of teaching and learning in technological processes such as analysing and designing PTS, there are other key elements embedded in the processes that need to be directed attention to. By adding a second-order perspective on technological knowledge derived from the knowledge domain of PTS, this thesis contributes knowledge about what these key elements are i.e. knowledge of the dual nature of PTS, as well as knowledge of the programming materials used for representing PTS. Further, contextual appreciation and systems thinking are important elements for the learning of technology in the processes. Together, the identified key elements direct attention to the structural and functional nature of PTS and aspects that are critical to discern, both in an everyday context and in the context of a programming material. In order to learn how PTS work and are controlled by programming, pupils need to discern critical aspects of PTS in the contexts in which they are presented, and to experience these as a cohesive and detailed part-whole structure. Contextual appreciation directs attention to the relevance structure brought to the learning situation by the different contexts, and the conditions these provide to experience the part-whole structure of PTS. Systems thinking may help pupils to experience the part-whole structure of PTS in a powerful way, as well as helping them to compare and see differences and similarities between parts and parts, and between whole and whole, in the different contexts. This provides the prerequisites to transcend the contextual details and move towards a general understanding of PTS that can be applied in any context, to see what happens in between input and output. Consequently, the implication is that for pupils to understand PTS, it is necessary for them to develop their ability to see the parts of PTS, in order to understand the whole, in any context

Chapter 8: Swedish summary

Digital teknik har blivit en stor del av våra dagliga liv och vi är allt mer beroende av tekniska lösningar som styrs av programmering, s.k. programmerade tekniska lösningar eller PTS (Programmed Technological Solutions). De flesta använder dessa tekniska lösningar för att uppfylla olika ändamål, utan att egentligen reflektera över hur de fungerar (Compton & Compton, 2013; Svenningsson, 2019). Dakers och De Vries (2019) beskriver detta som "black-boxing-syndromet", dvs intresset riktas enbart mot input och output, utan att ägna uppmärksamhet åt de processer och den kunskap som ligger bakom de tekniska lösningarna. Att ”black-boxa” tekniken kan vara en strategi för att lättare kunna ta till sig teknikens funktioner, men samtidigt kan det också utgöra en risk. Om vi enbart blir användare av tekniken utan att förstå den teknik vi använder, riskerar vi i allt större utsträckning hamna i händerna på de få som faktiskt förstår sig på tekniken och även utvecklar den. Att inte förstå processerna och kunskapen bakom tekniken resulterar även i att det blir svårt att kritiskt analysera och utvärdera tekniken. Med andra ord behöver vi kunna mer än att bara använda den digitala tekniken, vi behöver även förstå hur den fungerar. I detta sammanhang har grundskolans teknikundervisning ett viktigt syfte att uppfylla. Detta är att utveckla elevers förståelse av hur digital teknik och PTS i deras vardag fungerar. Programmering och PTS har således implementerats som innehåll i grundskolans teknikämne. I undervisningen förväntas elever lära sig hur tekniken fungerar genom att delta i aktiviteter där de får analysera befintliga PTS, och även designa egna PTS som de styr med programmering. Implementeringen har dock blivit en utmaning för många lärare, dels kring vad som ska undervisas, men även kring hur man ska undervisa. Vidare visar forskning att lärare förväntar sig att elever utvecklar mer generiska färdigheter såsom samarbetsförmåga, generell problemlösningsförmåga och datalogiskt tänkande då de deltar i olika programmeringsaktiviteter i undervisningen (Nouri m.fl., 2020). Så även om teknikämnet syftar till att utveckla elevers tekniska kunskaper i relation till PTS, är det inte självklart att undervisningen riktar sin uppmärksamhet mot detta. Följaktligen finns det ett behov av att diskutera och reflektera kring undervisning och lärande i relation till programmering och PTS utifrån ett teknikdidaktiskt perspektiv. Detta bör göras utifrån vad som karakteriserar teknik och grundskolans teknikämne, samt utifrån vilken teknisk kunskap eleverna förväntas lära sig, och hur de lär sig detta i processer som att analysera och designa PTS. I dagsläget är det brist på teknikdidaktisk forskning som riktar sig mot dessa frågor. Därför har denna avhandling för avsikt att utifrån ett teknikdidaktiskt perspektiv rikta uppmärksamhet mot innehållsliga aspekter i teknikundervisning i relation till PTS. Det som ligger till grund för avhandlingen är ett relationen mellan elever och PTS, dvs. elevers erfarande av PTS när de analyserar och designar PTS.

Syfte och forskningsfrågor

Det övergripande syftet med denna avhandling är att, från ett teknikdidaktiskt perspektiv och utifrån en empirisk bas, identifiera nyckelelement att lyfta fram i undervisningen då elever lär sig teknik i relation till programmerade tekniska lösningar. För att kunna identifiera dessa element tar avhandlingen utgångspunkt i den kunskapsdomän som innefattar kunskap i relation till PTS. Tillsammans med den empiriska bas utgörande av tre studier som undersöker elevers relation till PTS, söker avhandlingen svar på följande övergripande forskningsfråga:

- Vilka nyckelelement är viktiga att lyfta fram i undervisningen när elever lär sig teknik i relation till programmerade tekniska lösningar (PTS) i processer som analys och design av PTS?

Det empiriska arbetet har genomförts inom ramen för den svenska grundskolan och dess kursplan i teknik. I studierna deltog elever i åldrarna 10-14 år. Programmeringsmaterialet BBC micro:bit användes som kontext i de undersökta processerna. För att söka svar på den övergripande forskningsfrågan har elevers erfarande av PTS undersökts inom de tre ingående studierna, vilka relaterar till följande tre forskningsfrågor:

- Vilka är elevers skilda sätt att förstå PTS när de analyserar struktur och funktion? (Paper 1)
- Vilken teknisk kunskap behöver elever, i termer av kritiska aspekter, när de designar och kodar en PTS med BBC micro:bit? (Paper 2)
- På vilket sätt erfar elever sekventiellt centrala fenomen när de designar PTS med BBC micro:bit, och vilken effekt har erfarandet på hur processen utvecklar sig? (Paper 3)

Bakgrund

Förståelsen av teknikens karaktär och vad teknisk kunskap är, påverkar hur teknikundervisningen utformas samt vilket innehåll som uppmärksammas. Implementeringen av programmering och PTS i teknikundervisningen har kommit att rikta stor uppmärksamhet mot att lära elever programmera. Många lärare känner sig dock osäkra kring hur undervisning relaterat till programmering kan utformas, och vad eleverna ska lära sig (Lärarnas Riksförbund, 2017; Sentance & Csizmadia, 2017; Webb m.fl., 2017; Vinnervik, 2020). En studie av Nouri m.fl. (2020) visar att många lärare förväntar sig att elever ska lära sig mer generella förmågor såsom samarbetsförmåga, generell problemlösnings-förmåga och datalogiskt tänkande när de arbetar med olika programmeringsaktiviteter. Det är dock viktigt att komma ihåg att inom svensk skola har programmering implementerats som del av befintliga ämnen såsom matematik och teknik, vilkas kursplaner syftar till att utveckla ämnesspecifika kunskaper. Teknikämnet syftar bl.a. till att utveckla elevers tekniska kunskaper i relation till hur PTS fungerar och kan styras av programmering, vilket innefattar både konceptuell och procedurell teknisk kunskap. Det är med andra ord viktigt att inte tappa kontakten med vad teknik är och vad teknikundervisning bör vara. Viktiga element behöver identifieras och lyftas fram i teknikundervisningen för att skapa de förutsättningar som är nödvändiga för att elever ska kunna utveckla förståelse av hur PTS fungerar. För kunna identifiera viktiga element i relation till PTS i teknikundervisningen, tar denna avhandling utgångspunkt i det som utgör grunden för den tekniska kunskap som teknikundervisningen ska behandla i skolan, dvs. teknisk bildning (Technological literacy). Teknisk bildning har sitt ursprung i teknikfilosofi och kan sägas vara den tekniska allmänbildning som alla människor behöver för att kunna förstå och hantera teknik i sin vardag.

Över tid har det co-evolutionella förhållandet mellan människa och teknik förändrats i en riktning som kan ses som negativ, med tanke på att människan i allt lägre utsträckning förstår hur själva tekniken fungerar (Stiegler, 1998). Vi har helt enkelt blivit okritiska konsumenter av den teknik som omger oss i vardagen (De Vries, 2005). Detta är vad Dakers och De Vries (2019) beskriver som "black-boxing-syndromet", vars innebörd pekar på hur människor som teknikkonsumenter bara är intresserade av input och output, och vad som händer däremellan anses inte som relevant. Skolans teknikundervisning har i detta sammanhang en viktig roll att fylla i att motverka detta "black-boxingsyndrom". Användarperspektivet på teknik behöver utvidgas till att innefatta även förståelse av den tekniska kunskap som finns gömd bakom tekniken. Det är alltså nödvändigt att utveckla elevernas kunskaper om själva tekniken i sig, för att de vidare ska kunna utveckla förmåga att kritiskt analysera den (Axell, 2019). Således är det viktigt att identifiera vad denna kunskap är.

Som en del av denna avhandling har därför avsikten varit att med utgångspunkt i teknikfilosofi, identifiera kunskapsområden i relation till undervisning kring PTS i processer som analys och design. Utifrån detta har följande tekniska kunskapsområden identifierats: systemisk kunskap och systemtänkande; konceptuell och procedurell kunskap i relation till processer som analys och design av PTS, såsom kunskap om strukturella och funktionella aspekter i relation till PTS, samt kunskap om input och output i termer av digital information i en teknisk lösning och hur man tolkar och styr ett sådant informationsflöde. Detta inkluderar kunskap i att programmera, dvs hantering av syntax och semantik i ett programmeringsspråk för att uppnå ett förväntat beteende hos PTS. Följaktligen finns det flera delar som är nödvändiga att förstå i relation till processer av analys och design av PTS.

Det är dock inte tillräckligt att bara identifiera kunskapsområden att ta upp i teknikundervisningen på grundval av kunskapsdomänen för PTS. När dessa kunskapsområden ska omvandlas till ett undervisningsbart innehåll utifrån kursplanen i teknik är det också nödvändigt att ta hänsyn till elevernas förhållande till innehållet (Bronäs, 2016). Tidigare forskning visar att lärande inte är en självklarhet i undervisningsaktiviteter där elever analyserar och designar PTS med olika programmeringmaterial (se t.ex. Ivarsson, 2003; Pea, 1983). Eleverna har bl.a. svårt att förstå strukturella och funktionella relationer, och har även svårt att tolka och kontrollera informationsflödet, dvs. förstå och använda programmering för att styra PTS (Mioduser m.fl., 1996; Slangen m.fl., 2011). Vidare anser Ginestié (2018) att det finns en risk i denna typ av aktiviteter då ett stort kognitivt fokus ägnas åt att lära sig programmera, vilket resulterar i att ett mindre fokus läggs på att lära sig annan teknisk kunskap. Elever behöver dessutom mycket stöd av läraren för att kunna utveckla kunskaper som kan ta dem bortom själva programmeringsaktiviteten (Ivarsson, 2003; Lye & Koh, 2014; Pea, 1983). Vidare beskriver Vinnervik (2020) hur dessa aktiviteter behöver gå utöver att bara vara enbart explorativa och roliga händelser, till att anpassas utifrån läroplanens avsikter. Annars riskerar lärandet i denna typ av aktiviteterna bli fragmentariskt, eller i värsta fall inget alls.

Tidigare forskning pekar på svårigheter som elever har när de analyserar och designar PTS. Den ger oss dock inte svar på vad som möjliggör lärande i dessa situationer, och vad som bör adresseras i undervisningen för att övervinna elevers svårigheter. Följaktligen finns behov av mer fördjupad kunskap kring elevers förståelse av PTS, och hur denna förståelse utvecklas i situationer där elever analyserar och designar PTS. Utifrån behovet av kunskap kring elevers förståelse av PTS, utgår avhandlingens tre empiriska studierna från det fenomenografiska perspektivet på lärande. Syftet är att undersöka elevers erfarande av PTS då de analyserar och designar PTS. I nästa avsnitt beskrivs de premisser och teoretiska antaganden som ligger till grund för de fenomenografiska studierna inom avhandlingen.

Fenomenografi

Den fenomenografiska forskningsansatsen har utvecklats i ett pedagogiskt sammanhang och har bidragit med pedagogiskt värde genom att identifiera elevers förmåga att erfara ett fenomen, samt genom att identifiera vad elever behöver erfara för att utveckla en mer kraftfull förståelse av fenomenet (Åkerlind, 2015). Inom Fenomenografin innebär lärande att man utvecklar en förmåga att se fenomenet på ett nytt sätt, annorlunda än tidigare. Att se i denna mening innebär att man kan urskilja viktiga aspekter av fenomenet. Dessa viktiga aspekter kallas kritiska aspekter, dvs. aspekter som är nödvändiga att urskilja för att erfara fenomenet på ett mer kraftfullt sätt (Marton & Booth, 1997). Att kunna urskilja de kritiska aspekterna av ett fenomen innebär dock att man behöver kunna skilja dem från andra mindre viktiga aspekter. För att kunna göra detta behöver eleverna erbjudas situationer där de presenteras för variation i förhållande till de kritiska aspekterna. För att kunna erbjuda dessa situationer behöver läraren ha kunskap om vad de kritiska aspekterna är. Denna kunskap kan erhållas utifrån fenomenografiska studier som studerar elevers erfarande av det specifika fenomenet. Genom att analysera och beskriva elevernas kvalitativt skilda sätt att erfara ett fenomen, erhålls i en fenomenografisk studie en uppsättning beskrivningskategorier som kan struktureras hierarkiskt. De olika beskrivningskategorierna karaktäriserar mer eller mindre komplexa sätt att erfara samma fenomen och kallas för utfallsrum. Inom utfallsrummet kan kritiska skillnader i erfarandet av fenomenet identifieras, dvs. de kritiska aspekterna. Resultatet kan användas i undervisningen för att bygga relevansstrukturer, vilket innebär att relevanta aspekter av fenomenet lyfts fram, samtidigt som irrelevanta aspekter ställs i bakgrunden. Detta kan hjälpa eleverna att erfara fenomenet på ett mer kraftfullt sätt.

I undervisningssituationer inom ämnen som fysik och teknik är det vanligt att tillhandahålla en mängd olika undervisningsmaterial såsom representationer, verktyg eller aktiviteter för att visualisera och underlätta förståelse av olika fenomen (se Airey & Linder, 2009). Exempel på detta kan vara modeller, bilder, konkreta material, eller aktiviteter som analys och design. Gemensamt för dessa är att de för med sig kontextuella faktorer som påverkar den relevansstruktur elever erfar i undervisningssituationen (Marton m.fl., 2004). Detta innebär att kontexten som erbjuds av dessa undervisningsmaterial indikerar ett visst sätt att erfara fenomenet, där dess aspekter framträder med mer eller mindre relevans. Således bör studier som undersöker elevers skilda sätt att erfara ett fenomen även rikta uppmärksamhet mot kontexten inom vilken fenomenet erfars. I en undervisningssituation skulle motsvarande innebära en medvetenhet om de kontextuella förhållanden som kan bidra till att utveckla elevers förmåga att urskilja kritiska aspekter av fenomenet. Läraren behöver således vara medveten om både vad de kritiska aspekterna är, samt medveten om i vilken utsträckning kontexten kan bidra till att elever kan urskilja kritiska aspekter av fenomenet (Marton & Pang, 1999). Genom att undersöka elevernas kvalitativt skilda sätt att erfara fenomenet i specifika undervisningskontexter, kan fenomenografiska studier bidra med kunskap om vad de kritiska aspekterna är, samt bidra med kunskap om i vilken utsträckning elever ges möjlighet att erfara fenomenet i de kontexter som erbjuds.

De ingående studierna inom denna avhandling undersöker elevers kvalitativt skilda sätt att erfara PTS då de analyserar och designar PTS. Anledningen till att jag valt dessa situationer är att det inom teknikundervisningen är vanligt att kontextualisera innehåll relaterat till PTS i aktiviteter som analys och design där olika programmeringsmaterial eller vardagsföremål används för att representera PTS. Utgångspunkt i avhandlingen är att dessa situationer innefattar teknisk kunskap relaterat till begrepp och processer som anses nödvändiga i den specifika kontexten (se McCormick, 2004). Detta innebär att i undervisningssituationer där elever erfar PTS som en kontextualiserad del, som i analys- och designprocesser, är kunskapens karaktär beroende av kontextuella faktorer såsom problemet som ska lösas, det programmeringsmaterial som används eller andra föremål som används för att visualisera PTS. Vidare, beskriver Lo (2012) att kontextuella faktorer påverkar den erfarna situationens relevansstruktur. Utifrån antagandet att lärande påverkas av undervisningssituationens relevansstruktur (se Ingerman m.fl., 2007; Lo, 2012; Marton & Booth, 1997; Marton m.fl., 2004; Marton, 2015), anses det därför viktigt att undersöka elevers sätt att erfara PTS som en del av situationer där förväntas lära sig teknik. Uppmärksamhet bör alltså även riktas mot de sammanhang där PTS erfars, då elevers erfarande undersöks. Detta innebär att uppmärksamhet i de fenomenografiska studierna inom avhandlingen riktas mot elevers erfarande av PTS som kontextualiserade i analys- och designprocessen, där olika representationer av PTS används såsom programmeringsmaterialet BBC micro:bit och PTS i form av vardagsföremål. De empiriska studierna undersöker således elevers kvalitativt skilda sätt att erfara PTS med avsikt att förstå del-helhetsstrukturen i erfarandet, samt hur kontexten påverkar erfarandet. Vidare har studierna för avsikt att identifiera vad som behöver läras i processerna i termer av kritiska aspekter. Resultaten av studierna ligger till grund för att kunna identifiera nyckelelement att lyfta fram i teknikundervisningen i relation till analys och design av PTS.

Forskningsdesign

Forskningsintresset i de empiriska studierna riktar sig mot elevers relation till undervisningsinnehållet PTS, dvs. elevers erfarande av PTS när de analyserar och designar PTS. Vid val av forskningsdesign lämpar sig därför den fenomenografiska forskningsansatsen inom vilken man studerar individers erfarande av fenomen. I Paper 1 undersöks elevers kvalitativt skilda förståelser av PTS då de analyserar struktur och funktion i PTS. I Paper 2 undersöks vilken teknisk kunskap elever behöver, i termer av kritiska aspekter, när de designar och kodar en PTS med BBC micro:bit. I Paper 3 undersöks elevers sekventiella erfarande av centrala fenomen när de designar PTS med BBC micro:bit, samt vilken effekt erfarandet har på hur processen utvecklar sig. Resultatet av studierna vävs sedan samman med de kunskapsområdena som identifierats utifrån kunskapsdomänen för PTS.

Inom avhandlingen har avgränsningar gjorts i relation till de forskningsfrågor som ställs. Jag valt att avgränsa forskningsfrågornas innehåll till att beröra teknikkunskaper och fenomenet PTS. Ytterligare en avgränsning är urvalet av elevgrupp. Jag har valt att studera elever i åldern 11–14 år som på olika sätt arbetat med PTS i undervisningen tidigare. Detta är även den åldersgrupp av elever som jag själv mött under min tid som lärare och vilka jag bedömer ha förmåga att uttrycka sin förståelse om PTS. Vidare har avgränsningar gjorts i relation till det specifika fenomen som studeras, för att säkerställa att eleverna talar om det av forskaren valda fenomenet. Avgränsning har gjorts mot teknisk kunskap och PTS, i relation till konstruerandet av fysiska tekniska lösningar som styrs med programmering, och i relation till analys av befintliga PTS. Eftersom både programmering och tekniska lösningar kan vara svårt att tydligt avgränsa på grund av dess komplexitet och innehållsliga koppling till flera olika områden har jag valt att använda mig av förberedda kontexter för att rama in vad som avses med PTS inom studierna (se Adawi m.fl., 2001). De förberedda kontexter har utgjorts av material och föremål som eleverna är bekanta med såsom programmeringsmaterialet BBC Micro:bit, och olika vardagsföremål som är programmerade såsom tv-fjärrkontroll, digital termometer och en bil-nyckel.

Datainsamling

Avhandlingens tre empiriska studier baseras på två datainsamlingar. Den första datainsamlingen består av semistrukturerade intervjuer med 23 elever i åldrarna 11-12 år, från två olika skolor. Denna typ av intervjuform är lämplig eftersom jag som forskare styr upp intervjun utifrån förutbestämda frågor, men det finns samtidigt utrymme för eleven att till viss del styra intervjun. Detta innebär att jag utifrån det som eleven svarar kan ställa följdfrågor för att få en fördjupad förståelse av det eleven svarar. Inför de semistrukturerade intervjuerna utvecklades en intervjuguide (bilaga 1), vilken pilottestades på ett antal elever och därefter revideras. Intervjuerna hölls enskilt med eleverna under skoltid. Samtliga intervjuer spelades in. Vid intervjuerna presenterades olika förberedda kontexter i form av BBC micro:bit konstruktioner och vardagsföremål som är programmerade, med syftet att rikta in intervjuinnehållet mot PTS.

Den andra datainsamlingen består av skisser, videoinspelningar, intervjuer vilka samlades in från en situation då elever arbetar med att konstruera en programmerad teknisk lösning. 8 elever från årskurs 4, och 6 elever från årskurs 8 deltog vid två skilda tillfällen. Eleverna arbetade i par och introducerades till en teknisk problemlösningsuppgift (Bilaga 5) där de med hjälp av BBC micro:bit-materialet skulle designa och koda ett tjuvlarm. Den första delen av uppgiften bestod i att diskutera och skissa på en idé till lösning med papper och penna. Nästa steg var att genomföra idén med hjälp av BBC micro:bit-materialet och använda en iPad eller dator för att koda. Eleverna i årskurs 4 använde datorer och eleverna i årskurs 8 använde iPads. Skisserna samlades in som data. Eleverna filmades medan de arbetade med uppgiften, och även ett skärminspelningsprogram användes för att spela in när eleverna kodade på iPad. Tyvärr var det inte möjligt att använda ett skärminspelningsprogram på datorerna på grund av begränsad åtkomst till programvara. Aktiviteten på datorskärmen fångades i stället av de andra kamerorna som filmade elevernas arbete med uppgiften. En mikrofon placerades framför varje elevpar för att fånga elevernas diskussioner. I samband med att eleverna arbetade med uppgiften ställde forskaren frågor (se Bilaga 3) vilka riktade elevernas fokus mot PTS. I direkt anslutning till att arbetet med uppgiften avslutats, hölls även semi-strukturerade intervjuer med varje elevpar utifrån en intervjuguide (Bilaga 3).

Analys

I den fenomenografiska analysen undersöks vilka delar av fenomenet eleverna riktar sitt fokus mot och urskiljer. På detta sätt kan viktiga aspekter identifieras som karakteriserar skilda sätt att förstå ett fenomen. Variationer i elevers sätt att erfara ett fenomen är således relaterat till skillnaderna i vad som upptäcks. Det kan vara så att fenomenets delar, förhållandena mellan delarna och hur de förhåller sig till hela fenomenet urskiljs på skilda sätt. Detta är vad Marton och Booth (1997) beskriver som strukturella aspekter av att förstå fenomenet. Erfarandet är också relaterad till fenomenets meningsbärande aspekter, dvs. referentiella aspekter, vilka Marton och Booth beskriver som nära sammanflätade med de strukturella aspekterna. De referentiella och strukturella aspekterna är närvarande i individens medvetande samtidigt då ett fenomen erfars. Med utgångspunkt i dessa premisser har alltså de fenomenografiska analysarbetet inom studierna genomförts. I relation till de beskrivningskategorier som utvecklats inom respektive utfallsrum har de strukturella och referentiella aspekterna identifierats med avsikt att förstå strukturen i elevers erfarande. På detta sätt kan en överblick fås av vad som karakteriserar elevers olika sätt att förstå eller erfara PTS då de analyserar och designar PTS. Genom att vidare undersöka skillnaderna mellan kategorierna i ett utfallsrum dvs. skillnaderna i elevernas erfarande av PTS, har också kritiska aspekterna kunnat identifieras.

Analysarbete tog således utgångspunkt i den fenomenografiska analysprocessen och baserades på empiriska data från de två datasamlingarna. I Paper 1, vilken är baserad på Datainsamling 1, såg analysarbetet ut enligt följande. I ett första skede lästes samtliga transskript igenom upprepade gånger för att få en helhetsbild av innehållet. Denna läsning visade att elevernas sätt att närma sig PTS skiljer sig åt, beroende på vilken av de förberedda kontexterna som eleverna presenterades inför, dvs. om det var BBC micro:bit-konstruktionerna eller PTS i form av vardagsföremål. Med anledning av detta delades analysen in i två delar baserat på de två kontexterna. Transkriberingarna från varje del av intervjuerna relaterat till de olika kontexterna lästes igenom upprepade gånger. Därefter valdes excerpt ut som representerade elevers skilda förståelser av PTS inom de två kontexterna. Dessa excerpt tolkades och sammanfördes i olika kategorier. Kategorierna analyserades och definierades sedan med avseende på de strukturella och referentiella aspekterna, vilka sammantaget representerade förståelsen inom varje kategori. Därefter testades data mot de definierade kategorierna för att justera definitionen av kategorierna. Elevernas skilda förståelser utgjorde två olika utfallsrum, dvs. två uppsättningar av kategorier i relation till de båda kontexterna; en för BBC micro:bit-konstruktioner, och en för PTS i form av vardagsföremål, var och en med fyra olika kategorier. Slutligen jämfördes de två utfallsrummen med varandra för att hitta likheter och skillnader. Därefter integrerades de i ett gemensamt utfallsrum. Inom utfallsrummet skiljer sig kategorierna kvalitativt från varandra, men är logiskt och strukturellt relaterade till varandra utifrån ökad komplexitet.

I Paper 2, vilken är baserad på Datainsamling 2, påbörjades analysarbetet genom att initialt undersöka vad elever fokuserar på i processen då de designar en PTS. Därefter undersöktes skillnader i elevers erfarande av PTS i processen. Detta gjordes genom att studera elevskisser, läsa igenom transkriberade intervjuer och att titta igenom videomaterialet. Först analyserades elevernas skisser genom att identifiera skillnader i elevers representationer av lösningar i skisserna. Utifrån detta kunde kategorier skapas som representerade variationen i skisserna. Därefter analyserades elevintervjuerna. Det transkriberade materialet lästes igenom flera gånger för att identifiera passager vilka visar på skillnader i elevers erfarande av att designa PTS. Excerpt valdes ut som visade på skillnaderna, vilka sedan tolkades och sammanfördes i kategorier utifrån deras innehåll. Nästa steg var att titta igenom video-inspelningarna för att finna sekvenser i materialet som visar på skillnader i elevers erfarande av att designa PTS. Dessa sekvenser transkriberades ordagrant tillsammans med beskrivningar av elevernas handlingar. Excerpt valdes ut som visade på skillnader i erfarande, vilka tolkades och sammanställdes i kategorier utifrån deras innehåll. Denna del av analysarbetet resulterade i ett bruttoutfall av kategorier som visar på skillnader i elevers erfarande. Utifrån detta bruttoutfall kunde två nära sammanflätade fenomen urskiljas; struktur och funktion i PTS, och BBC micro:bit materialet som representation av PTS. Elevers skilda erfarande av dessa två fenomen sammanställdes i två preliminära utfallsrum, vilka testades på insamlad data. Inom de två utfallsrummen analyserades och definierades kategorierna utifrån strukturella och referentiella aspekterna, vilka sammantaget representerade förståelsen inom varje kategori. Utifrån elevers skilda förståelser kunde även de kritiska aspekterna identifieras. De två utfallsrummen testades därefter på excerpten av transkriberad data samt elevskisserna, och justerades. Excerpt samt elevskisser valdes sedan ut, vilka representerar kategorierna inom de två utfallsrummen.

Även Paper 3 är baserad på Datainsamling 2. Analysen tog sin utgångspunkt från resultatet i Paper 2, där de kritiska aspekterna som identifierats användes som analytiskt ramverk. Syftet var att undersöka elevers sekventiella erfarande av centrala fenomen i termer av kritiska aspekter när de designar PTS, samt vilken effekt deras sätt att erfara har på hur processen utvecklas. Inledningsvis i analysen analyserades videomaterialet utifrån varje elevpar. Sekvenser identifierades där eleverna uttryckte sitt sätt att erfara fenomenen, både i handling och i ord. De identifierade sekvenserna transkriberades sedan ordagrant, tillsammans med beskrivningar av elevernas handlingar. Det transkriberade videomaterialet analyserades vidare i tre steg tillsammans med elevernas skisser, där de tidigare identifierade kritiska aspekterna från Paper 2 användes för att strukturera analysen på ett systematiskt sätt. Först kopplades de identifierade sekvenserna till de olika stegen i processen, dvs. planering och skissandet på lösning samt montering och kodning av PTS. Därefter riktades analysen mot elevers urskiljande av kritiska aspekter baserat på elevernas diskussioner och handlingar i de sekventiella delarna av processen, och huruvida de urskilda kritiska aspekterna tillkännagavs mening i relation till varandra. Slutligen riktades analysen mot processen som helhet och dess sekventiella utveckling, utifrån vilken effekt elevers sätt att erfara de centrala fenomenen har på hur processen utvecklas.

Resultat

Det sammanhållna resultatet baserat på de tre studierna och identifierade kunskapsområden i relation till PTS indikerar fyra huvudområden att rikta uppmärksamhet mot i teknikundervisningen. Dessa innefattar kunskap relaterad till den strukturella och funktionella karaktären i PTS, kunskap relaterad till det programmeringsmaterial som används i undervisningen för att representera PTS, medvetenhet om de kontextuella förutsättningarna och den relevansstruktur situationen erbjuder vid analys och design av PTS, samt användandet av systemtänkande för att kunna urskilja fenomenets del-helhetstruktur.

Det syntetiserade resultaten baserat på de enskilda studierna visar att det finns aspekter av PTS som är kritiska att urskilja för att kunna erfara PTS på ett kraftfullt sätt, både i analys- och designprocessen (Tabell 5). Resultaten i Paper 1 visar att elever erfar PTS utifrån samma kritiska aspekter inom de olika kontexterna, även om de initialt närmar sig kontexterna på olika sätt. Resultaten från Paper 2 och Paper 3 visar dock att elever erfar PTS i designprocessen utifrån två olika, men nära sammanflätade fenomen, dessa är PTS utifrån dess strukturella och funktionella karaktär, samt själva BBC micro:bit materialet som används i processen, och representerar aspekter av PTS.

Tabell 5 Aspekter som är kritiska att urskilja i analys- och designprocessen

Analys (Paper 1)	**Design (Paper 2)**	
PTS Struktur och funktion	PTS Struktur och funktion	BBC micro:bit materialet
Logiken i koden och hur den styr komponenterna	Logiken i koden - feedbackstyrning	Vad blocken representerar utifrån verkliga förhållanden i omgivningen, och i relation till programmerings-begrepp
Hur komponenterna fungerar och deras funktion i PTS	Hur komponenterna fungerar	Blockens form
Komponenternas organisation	Komponenternas organisation	Editorns organisation
Interaktionen mellan koden och komponenterna genererar ett flöde av information som bestämmer funktionen i PTS	Interaktionen mellan kod och komponenter som genererar ett flöde av information som styr funktionen i PTS	Behovet av en styrfunktion i koden och hur denna kan kombineras i termer av block för att kunna styra PTS.

(Utvecklad utifrån resultat Paper 1, Cederqvist 2020 och resultat Paper 2, Cederqvist 2020)

Resultatet visar att kontexterna inom vilka PTS erfars, dvs. inom BBC micro:bit kontexten och i kontexten av vardagsföremål, skapar specifika relevans-strukturer. Dessa riktar elevers uppmärksamhet till mer eller mindre relevanta aspekter av PTS, vilket påverkar hur elever erfar PTS. I Paper 1 när elever analyserar struktur och funktion utifrån PTS i BBC micro:bit kontexten erfar elever PTS inledningsvis som en helhet baserad på en interaktion mellan black-boxade delar vilken påverkar funktionen. Det finns dock en variation i elevers erfarande vilken är baserad på deras förmåga att urskilja kritiska aspekter av PTS såsom komponenternas funktion och hur dessa är organiserade, samt flödet av information i PTS. När elever analyserar struktur och funktion i kontexten av olika vardagsföremål erfar elever inledningsvis PTS utifrån deras enskilda komponenter, och utifrån vad PTS kan göra, dvs. deras funktion. Även här finns en variation i elevers erfarande utifrån deras förmåga att urskilja kritiska aspekter av PTS såsom organisation av komponenter och flöde av information. Resultaten visar att relevansstrukturerna som de olika kontexterna erbjuder påverkar elevers sätt att erfara PTS. Detta innebär att elever inledningsvis närmare sig PTS på olika sätt i de två kontexterna, utifrån vilka aspekter av PTS som blir mer eller mindre framträdande och relevanta.

Således visar resultaten att elevernas olika sätt att erfara PTS baseras på i vilken utsträckning de kan urskilja de kritiska aspekterna av PTS i de olika kontexterna. Vidare indikerar resultaten att erfarandet av PTS i den ena kontexten, påverkar erfarandet i den andra kontexten. Om vi tänker oss att BBC micro:bit kontexten används som en representation för att utveckla förståelse av PTS i en vardagskontext, indikerar detta ett behov av medvetenhet kring hur elever erfar själva BBC micro:bit kontexten utifrån den relevansstruktur som erbjuds. Resultaten visar att elever behöver göras medvetna om likheter och skillnaderna mellan de två kontexterna inom vilka PTS erfars. Detta skapar förutsättningar för att kunna överskrida de kontextuella detaljerna och därmed också förutsättningar för att generalisera förståelsen för PTS.

Både Paper 2 och Paper 3 baseras på Datainsamling 2 där eleverna presenterades inför en teknisk problemlösningsuppgift med utgångspunkt i en vardagskontext. De fick i uppgift att designa ett tjuvlarm med hjälp av BBC micro:bit. Resultaten visar att eleverna i processen rör sig fram och tillbaka mellan vardagskontexten och BBC micro:bit-kontexten när de arbetar med uppgiften. Resultaten visar även att elevernas förmåga att genomföra uppgiften beror på i vilken utsträckning de kan urskilja kritiska aspekter i relation till PTS inom de båda kontexterna. Sammantaget kan man beskriva denna process som att eleverna behöver överföra erfaren struktur och funktion av PTS i vardagskontexten till BBC micro:bit kontexten. Inledningsvis innebär detta att eleverna behöver kunna urskilja kritiska aspekter av struktur och funktion i den PTS de har för avsikt att designa, utifrån förhållanden i den vardagskontext den ska användas. För att komma vidare i processen behöver de överföra avsedd struktur och funktion till BBC micro:bit-kontexten. Detta innebär att de behöver kunna urskilja kritiska aspekterna av BBC micro:bit-materialet, i relation till analyserad struktur och funktion av PTS i vardagskontexten. Således förväntas eleverna urskilja båda dessa fenomens del-helhetsstrukturer och matcha dem till en sammanhängande helhet i processen, för att åstadkomma en fungerande PTS. För att kunna genomföra detta måste eleverna kunna urskilja likheter och skillnader mellan de två kontexterna i relation till strukturella och funktionella aspekter av PTS. Därmed behöver de kritiska aspekterna sättas i relation till varandra, och till hela processen av att designa PTS med BBC micro:bit materialet. Resultaten visar således att elevernas sätt att erfara PTS är beroende av kontextuella faktorer i analys- och designprocesserna. Elevernas förmåga att urskilja kritiska aspekter av PTS är beroende av den relevans-struktur som kontexten bidrar med i situationen. För att kunna överskrida de kontextuella faktorerna och för att generalisera förståelsen av PTS behöver eleverna lära sig att se skillnader och likheter mellan de erfarna del-helhets-strukturerna i kontexterna.

Resultaten visar även att när elever närmar sig PTS som representerade i de två kontexterna och försöker urskilja dess del-helhetstruktur, verkar de anta olika nivåer av systemtänkande. Detta pekar på att systemtänkande kan vara en strategi som hjälper elever att erfara PTS på ett kraftfullt sätt i analys- och designprocessen. När elever presenteras för PTS i olika kontexter erfars PTS initialt som flera odifferentierade helheter av vilka eleverna utmanas att urskilja dess delar. I Paper 1 använder sig t.ex. elever inledningsvis av en "black-boxing"-strategi då de inte kan urskilja aspekter som logiken i koden eller komponenternas organisation. Även om strategin inte är hållbar för att förstå PTS på ett mer kraftfullt sätt, hjälper strategin dem att erfara funktionen av PTS. När de analyserar PTS i vardagskontexten använder de ett mer användar-drivet tillvägagångssätt. Detta baseras på elevernas tidigare erfarenhet av PTS och användandet av enskilda komponenter som t.ex. knappar eller strömbrytare och hur dessa påverkar funktionen. Resultaten i Paper 1 visar att ju mer eleverna kan urskilja av de ingående delarna och hur dessa samverkar, desto kraftfullare blir elevernas förståelse av PTS i de båda kontexterna. I Paper 2 visar resultaten att elever närmar sig struktur och funktion i PTS utifrån olika nivåer av system-tänkande. Inledningsvis "black-boxar" de strukturella delar av PTS såsom koden och organisationen av komponenter för att förstå funktionen. Ju fler ”black-boxade” delar som öppnas upp, desto kraftfullare blir elevernas sätt att erfara både struktur och funktion.

Resultaten av studierna visar även att om PTS i termer av odifferentierade helheter i de olika kontexterna inte erfars i termer av dess delar, och kritiska aspekterna inte urskiljs, så blir det svårt för eleverna att ta sig vidare, både i analysprocessen och i designprocessen. Detta gäller både då de ska slutföra uppgifterna och att förstå hur PTS fungerar. Paper 3 visar exempel på hur elever sekventiellt erfar processen av att designa en PTS. Resultatet visar att ju fler kritiska aspekter eleverna kan urskilja i termer av struktur och funktion av PTS, desto bättre förutsättningar har de att kunna åstadkomma sitt larm. Det krävs dock att eleverna även kan urskilja kritiska aspekter i relation till BBC micro:bit-materialet samt att de kan koppla dessa till strukturella och funktionella aspekter av PTS. Med andra ord, ju fler aspekter som urskiljs, samt hur dessa är relaterade till varandra, desto kraftfullare är erfarandet av PTS i processen. Slutligen finns det således tillräckligt med detaljer och sammanhållning i elevernas förståelse av PTS, vilket också gör det möjligt för dem att producera deras avsedda PTS.

Resultaten indikerar att systemtänkande kan underlätta rörelsen mellan strukturella och funktionella aspekter av PTS. Vidare indikerar resultaten att systemtänkande även kan underlätta förflyttningen mellan PTS som representerad i vardagskontexten, till PTS representerad i BBC micro:bit-kontexten, och tvärt om. En grundlig förståelse av den strukturella och funktionella karaktären av PTS är en förutsättning för att kunna se de strukturella och funktionella delarna av PTS både i BBC micro:bit-kontexten och i en vardagskontext. När elever erfar del-helhetstrukturen av PTS i de olika men anslutande kontexterna, verkar således systemtänkande hjälpa dem jämföra del-helhetstrukturerna med varandra för att urskilja skillnader och likheter mellan delar och delar, och mellan helhet och helhet. På detta sätt verkar systemtänkande även hjälpa elever att överskrida innebörden av de olika kontexterna mot en generell förståelse av PTS.

Sammanfattning av avhandlingens resultat

Det sammantagna resultaten, baserat på de tre empiriska studierna visar ett samband mellan de aspekter av PTS som är kritiska att urskilja, den relevans-struktur som kontexten indikerar, och systemtänkande som en strategi för att kunna erfara PTS på ett kraftfullt sätt i analys- och designprocesser. Utifrån ett teknikdidaktiskt perspektiv har detta sammantagna resultat vägts samman med identifierade kunskapsområden i relation till PTS. Följande nyckelelement har identifierats, vilka bör adresseras i undervisningen när elever lär sig teknik i processer som analys och design av PTS:

1. Kunskap relaterad till struktur och funktion i PTS, vilket innefattar:

- Kunskap om feedbackstyrning
- Kunskap om komponenter såsom sensorer, processor etc.
- Kunskap om hur komponenter kan organiseras för att åstadkomma funktionen i en PTS
- Systemkunskap för att förstå interaktionen mellan kod och komponenter vilken genererar ett flöde av information som styr funktionen i PTS
- Kunskap om hur man tolkar och styr flödet av information i PTS, dvs. kunskap om programmering och programmerings-begrepp

2. Kunskap relaterad till det programmeringsmaterial som används i undervisningen för att representera PTS likväl som för att designa PTS (i denna avhandling BBC micro:bit), vilket innefattar:
   - Kunskap om hur struktur och funktion av PTS är representerat i form av block, motsvarande förhållanden i verkligheten
   - Kunskap om programmeringsbegrepp för att kunna styra flödet av information i PTS och hur dessa är representerade av block
   - Kunskap om hur man kan använda programmeringsmaterialet i termer av dess struktur och funktion såsom att kunna tolka blockens form samt editorns organisation
   - Kunskap om ur man producerar kod genom att kombinera block till en styrfunktion som matchar t.ex. feedbackstyrning

3. Medvetenhet kring den relevansstruktur som erbjuds i undervisningssituationer utifrån olika kontexter såsom programmeringsmaterial och andra föremål som representerar PTS i processerna. Detta innebär att rikta uppmärksamhet åt den strukturella och funktionella karaktären av PTS, både i relation till programmeringsmaterialet och i relation till vardagskontext, vilket innefattar:
   - Aspekter av programmeringsmaterialet i relation till aspekter av PTS i en vardagskontext i termer av struktur och funktion, t.ex. block som representerar verklighetsförhållanden i relation till PTS, eller hur block representerar programmeringsbegrepp i relation till styrandet av funktionen i PTS.
   - Likheter och skillnader mellan PTS i kontexten av ett programmeringsmaterial och PTS i en vardagskontext (för att kunna transferera förståelse mellan kontexterna, och för att kunna överbrygga kontexterna och utveckla en generell förståelse av PTS).

4. Systemtänkande (dvs. att se PTS som ett tekniskt system) för att underlätta elevers erfarandet av PTS i termer av dess del-helhetstruktur, samt för att underlätta överbryggandet av kontexter för att utveckla generell förståelse av PTS. Detta innefattar:
   - Förståelse av delarna i PTS och förstå hur delarna samverkar, i relation till PTS som helhet.
   - Kunna se del-helhetsstrukturen av PTS i olika kontexter.
   - Kunna jämföra och se skillnader och likheter mellan del-del och helhet-helhet i olika kontexter.

Diskussion och slutsats

Denna avhandlingen bidrar med kunskap som har betydelse för både teori och praktik inom teknikundervisningen. Det huvudsakliga kunskapsbidraget består i de nyckelelement som bör adresseras i teknikundervisningen för att elever ska utveckla förståelse av hur PTS fungerar och kan styras av programmering.

Resultaten visar att förstå programmering och att kunna producera kod är viktiga element i de tekniska processer som avhandlingen undersöker, men det finns även andra viktiga element inbäddade i processerna som behöver riktas uppmärksamhet mot i undervisningen. Detta är kunskap om struktur och funktion i PTS, såväl som kunskap om det programmeringsmaterial som används för att representera aspekter av PTS i processerna. Dessutom bör kontexten uppmärksammas inom vilken PTS erfars. Tillsammans med systemtänkande är dessa viktiga element för att säkerställa lärandet av teknik i processerna. Tidigare studier visar att lärande inte kommer per automatik i denna typ undervisningsaktiviteter (Ivarsson, 2003; Pea, 1983). Elever behöver mycket stöd av läraren för att kunna slutföra uppgifterna, och eleverna lägger stort fokus på att producera själva koden, och mindre fokus ägnas åt att lära sig annan teknisk kunskap (Ginestié, 2018). Avhandlingen kan, utifrån sina resultat, bidra med den precision som kan behöva erbjudas i undervisningen för att skapa förutsättningar att elever lär sig teknik i relation till PTS, när de analyserar och designar PTS med ett programmeringsmaterial som BBC micro:bit.

De identifierade nyckelelementen riktar sin uppmärksamhet mot den strukturella och funktionella karaktären i PTS, och de aspekter som är kritiska att urskilja, både i en vardagskontext och i relation till ett programmeringsmaterial. För att elever ska lära sig hur PTS fungerar måste de kunna urskilja kritiska aspekter av PTS i de kontexter de presenteras, och erfara dessa som en sammanhängande och detaljerad helhetsstruktur. Genom att rikta uppmärksamhet mot kontexten och den relevansstruktur som de olika kontexterna erbjuder i inlärningssituationen, kan elever ges förutsättningar att erfara del-helhetsstrukturen av PTS. Systemtänkande kan hjälpa elever att erfara del-helhetsstrukturen av PTS på ett kraftfullt sätt, likväl som det kan hjälpa dem att jämföra skillnader och likheter mellan PTS i de olika kontexterna. Baserat på Marton's resonemang (2006) kan man således sammanfatta detta som att ett mer kraftfullt erfarande av PTS i de olika men relaterade kontexterna, skapar förutsättningar att överskrida de kontextuella detaljerna mot en generell förståelse av PTS vilken kan tillämpas i nya kontexter där PTS förekommer.

Sammanfattningsvis kan man säga att för elever ska utveckla förståelse om hur PTS fungerar, behöver de lära sig att se delarna och förstå dem, detta för att de ska kunna förstå helheten, i de olika kontexter PTS förkommer. Lärare behöver vara medvetna om vilken kunskap som är i spel och vad som är kritiskt att urskilja för att utveckla förståelse, då elever arbetar med uppgifter som innefattar analys och design av PTS. Lärare behöver även vara medvetna om i vilken utsträckning kritiska aspekter av fenomenet, dvs. PTS, kan urskiljas i de kontexter som erbjuds i undervisningssituationen (se Ingerman m.fl., 2007; Lo, 2012; Marton m.fl., 2004; Marton, 2015). Den här avhandlingen bidrar med kunskap om vad som är kritiskt för elever att urskilja då de analyserar och designar PTS, samt i vilken utsträckning elever erfar dessa i de undersökta kontexterna utifrån den relevansstruktur som erbjuds. Givet den begränsade grupp av elever samt de få kontexter som undersökts, behövs mer forskning inom området. Vidare behöver framtida forskning även rikta fokus mot teknisk bildning i relation till förmågan att kritiskt kunna analysera och utvärdera digital teknik. Detta innebär bl.a. ett fokus på digital teknik i termer av möjligheter och risker, framför allt i relation till hållbar utveckling och vilka konsekvenser digital teknik har på människa, samhälle och miljö.

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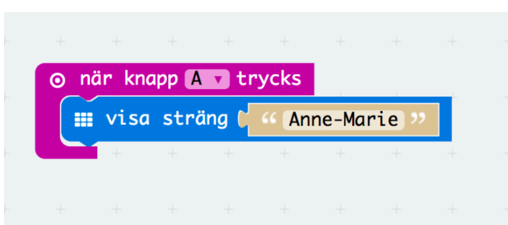
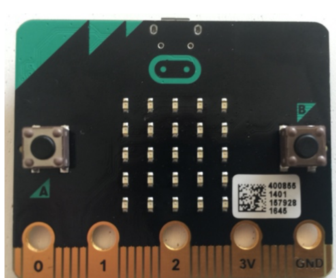
Appendix 1

Interview guide for Data Collection 1 (Paper 1)

A programmed technological solution: the name badge
I will show you a name badge that I have constructed with a micro:bit.
[I show a micro:bit and wires, and show the code on the computer screen]

- Have you programmed with the BBC micro:bit before?
- Take a look at this code [show the code on the screen]
- Can you describe for me how my name badge works, i.e. how it starts and how it can achieve its function? [input, feedback, process-code, output]
- Can you describe anything that might go wrong when you are constructing the name badge, which will cause it not to function? [code, components, interaction]
- Can the name badge work without the code? Can you explain?

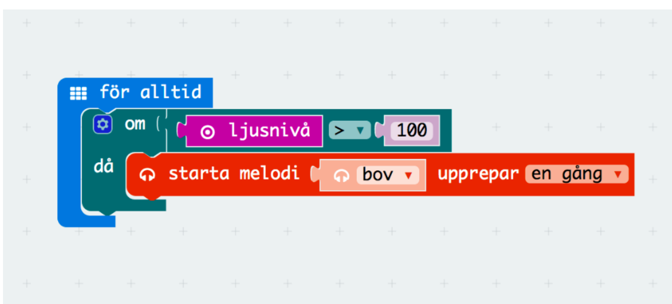




A programmed technological solution: the burglar alarm

I will show you a burglar alarm that I have constructed with a micro:bit, which I would be able to use in a refrigerator. [I show a micro:bit, wires, and a speaker, and show the code on the computer screen.] The LED-display on the micro:bit also works as a light sensor [show on the micro:bit].

- Take a look at this code [show the code on the screen]
- Can you describe for me how the burglar alarm works, i.e. how it starts and how it can achieve its function? [input, feedback, process-code, output]
- Can you describe anything that might go wrong when you are constructing the burglar alarm, which will cause it not to function? [code, components, interaction]
- Can the burglar alarm work without the code? Can you explain?



Final question on the micro:bit constructions

- If you compare the name badge with the burglar alarm, are there any differences between them regarding how the code makes them function? What are the differences?

Programming in everyday life

I will show you some objects that I have brought with me. [I show a TV remote control, a digital thermometer, a remote-controlled car key.]

- Are any of those programmed? Why do you think that? Choose one. [The pupil choose one object that we further discuss.]
- Can you describe how it [the chosen object] works, i.e. how it starts and how it can achieve its function? [input, feedback, process-code, output]
- Can you describe anything that may go wrong when you are constructing this [the chosen object], that will cause it not to function? [code, components, interaction]
- What similarities are there between how this [the chosen object] is programmed, and how any of the two micro:bit constructions are programmed? What is/are the difference/differences?
- Can you give me an example of anything else that is programmed in society?
- Can you describe how it [the chosen example] works, i.e. how it starts and how it can achieve its function? [input, feedback, process-code, output]
- Can you describe anything that may go wrong when you are constructing this [the chosen example], which will cause it not to function? [code, components, interaction]

- What similarities are there between how this [the chosen example] is programmed, and how any of the two micro:bit constructions are programmed? What is/are the difference/differences?
- Who programs it [the chosen example]? Does it matter who programs it? Why?
- Are there any risks with things that are programmed? What could happen?

Appendix 2

Written consent form for Data Collection 1 (Paper 1)

Hej!

Jag heter Anne-Marie Cederqvist och är forskarstuderande på Göteborgs Universitet. I mitt avhandlingsarbete intresserar jag mig för elevers förståelse av syftet med programmering och dess struktur och logik, i relation till tekniska system. Under vårterminen och höstterminen 2018 kommer jag inom ramen för mitt avhandlingsarbete genomföra studier på tre olika skolor med elever i åk 4 - 6. Jag kommer samla in forskningsmaterial genom att spela in intervjuer med elever. Varje intervju beräknas ta 30 – 45 minuter. Jag vill betona att det inte är enskilda elevers förståelse som är mitt forskningsfokus utan fokus är den variation av förståelse av programmering, som finns inom åldersgruppen. Samtliga intervjuer kommer skrivas ut av mig. Eleverna kommer vara anonyma och därför ges fingerade namn i de utskrivna versionerna. De utskrivna intervjuerna kommer analyseras av mig, tillsammans med mina handledare, Åke Ingerman, Göteborgs Universitet och Maria Svensson, Göteborgs Universitet samt utgöra underlag för diskussion i forskningsseminarier kring elevers förståelse av programmering.

Jag garanterar att studien genomförs i enlighet med Vetenskapsrådets forskningsetiska principer för humanistisk-samhällsvetenskaplig forskning. Detta innebär att insamlat material (ljudinspelningar) hanteras med respekt för individens integritet och kommer förvaras på en säker plats, oåtkomligt för obehöriga. (Läraren) har gett sitt samtycke att elever från klass (xx) på x-skolan medverkar i studien. Elevernas medverkan är dock frivillig och de kan när som helst under studien avbryta sin medverkan. För medverkan behövs ett skriftligt samtycke inhämtas från elevernas vårdnadshavare. Därför finns bifogat en samtyckesblankett som jag ber er fylla i och lämna till klassläraren snarast möjligt. Hör gärna av er på telefon eller via mail om ni har några frågor.

Med vänliga hälsningar

Anne-Marie Cederqvist

Doktorand vid institutionen för didaktik och pedagogisk profession (IDPP)

Utbildningsvetenskapliga fakulteten

Göteborgs universitet

Tel: 0707–444589 Mail: anne-marie.cederqvist@gu.se

Samtyckandeblankett

Jag har tagit del den skriftliga informationen angående forskningsstudien som ska genomföras på x-skolan under VT 2018 samt HT 2018, där Anne-Marie Cederqvist kommer använda ljudinspelningar för att dokumentera elevers förståelse av hur programmering kan användas som ett verktyg för att styra tekniska system.

Elevens namn:

____

☐ Jag ger mitt samtycke till att mitt barn medverkar i forskningsstudien.

☐ Jag ger inte mitt samtycke till att mitt barn medverkar i forskningsstudien.

Datum: ____________________

Vårdnadshavares underskrift:

____

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Appendix 3

Interview guide for Data Collection 2 (Paper 2 and Paper 3)

Questions that the pupils were asked during their work with the task and in the following semi-structured interview:

- Can you describe what components you use in your solution? How do they work? How do you use them? What function do the various components have?

- If we take a look at what you have written in the code, what do you attempt to achieve with this code? What function does the code have? Is there any connection between the code and the components and if there is, what is this connection?

- Can you show and describe how your solution for a burglar alarm works, i.e. how it starts and how it can function in the way it does?

- Was there anything that went wrong when you were assembling and coding the alarm that caused it not to work?

- What was difficult when you worked with the task? Did the PTS turned out as expected according to your sketch? What could you have done differently?

Appendix 4

Written consent form for Data Collection 2 (Paper 2 and Paper 3)

Till vårdnadshavare för elever i klass X på Y-skolan

Hej!
Jag heter Anne-Marie Cederqvist och är doktorand på Göteborgs Universitet. I mitt avhandlingsarbete intresserar jag mig för elevers förståelse av programmering i tekniska lösningar, inom skolans teknikämne. Under vår- och höstterminen 2019 kommer jag inom mitt avhandlingsarbete genomföra en studie med elever i grundskolan för att studera elevers förståelse av programmerade tekniska lösningar när de arbetar med att konstruera en egen teknisk lösning som de styr med programmering. Jag kommer samla in forskningsmaterial genom videofilmning och ljudupptagning när eleverna arbetar med en uppgift samt vid intervjuer med eleverna efter slutförd uppgift. Jag kommer även samla in skisser som eleverna gör i samband med uppgiften. Arbetet med uppgiften beräknas ta ca 30-45 minuter och efterföljande intervju ca 15 min. Jag vill betona att det inte är enskilda elevers förståelse som är mitt fokus, utan fokus är den variation av förståelse av programmerade tekniska lösningar, som finns inom åldersgruppen.

Filmer och intervjuer kommer att transkriberas (skrivas ut) av mig. Forskningsmaterialet kommer sedan analyseras av mig tillsammans med mina handledare, Åke Ingerman och Maria Svensson vid Göteborgs Universitet, samt utgöra underlag för diskussion i seminarier kring elevers förståelse av programmerade tekniska lösningar. Allt arbete inom studien kommer att ske i enlighet med Vetenskapsrådets forskningsetiska principer för humanistisk-samhällsvetenskaplig forskning och i enlighet med Dataskydds-förordningen (GDPR, 2016/679a)[1]. Detta innebär att insamlat material såsom elevskisser samt video- och ljudinspelningar, vilket räknas som personuppgifter, hanteras med respekt för individens integritet. och förvaras på sätt som innebär att obehöriga inte kan få tillgång till dem. De elever som medverkar på inspelningarna kommer att vara anonyma i den rapportering som kommer ut av studien. Namn kommer att ändras till fiktiva namn i de texter som publiceras. Om bilder från videoinspelningarna används vid rapporteringar kommer även de att anonymiseras så att personerna inte är möjliga att känna igen.

Rektor och ansvarig lärare, XXX, har gett sitt samtycke till att elever från klass X på Y-skolan medverkar i studien. Elevernas medverkan är frivillig och de kan när som helst under studien avbryta sin medverkan. För medverkan behövs ett skriftligt samtycke inhämtas från elevernas vårdnadshavare. Bifogat finns en samtyckesblankett som jag ber er fylla i och lämna till klassläraren.

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[1] Dataskyddsombud för Göteborgs universitet är Kristina Ullgren. Kristina.Ullgren@gu.se. Ansvarig för personuppgifterna är Göteborgs universitet.

Vid frågor hör av er på telefon 0707–444589 eller via mail: anne-marie.cederqvist@gu.se

Med vänliga hälsningar
Anne-Marie Cederqvist

Samtyckesblankett

Jag har tagit del av den skriftliga informationen angående studien som ska genomföras på x-skolan under vårterminen och höstterminen 2019, där Anne-Marie Cederqvist vid Göteborgs universitet kommer använda video- och ljudinspelningar samt elevskisser för att dokumentera elevers förståelse av programmerade tekniska lösningar.

Samtycket är giltigt tills vidare. Du har rätt att när som helst ta tillbaka ditt samtycke, vilket du gör genom att kontakta Anne-Marie Cederqvist. I så fall kommer de personuppgifter som har samlats in med stöd av detta samtycke upphöra att behandlas. Uppgifter som ingår i resultat som redan har åstadkommits kommer dock inte påverkas av att samtycket återkallas.

Elevens namn:

____

☐ Jag ger mitt samtycke till att mitt barn medverkar i forskningsstudien.
☐ Jag ger inte mitt samtycke till att mitt barn medverkar i forskningsstudien.

Datum: ____________________

Vårdnadshavares underskrift:

__________________________ __________________________

Namnförtydligande

__________________________ __________________________

Appendix 5

The pupils' task in Data Collection 2 (Paper 2 and Paper 3)

Designing and coding a burglar alarm using BBC micro:bit

The task: I have had a problem with someone stealing candy from my kitchen cabinet. I need your help to design a burglar alarm that is activated as soon as anyone opens the cabinet door.

Material: The BBC micro:bit material including a micro:bit, speakers, wires, batteries, battery holder, and an iPad or a computer from which you can program the micro:bit.

1. Sketch a solution where you show how you plan to assemble the alarm and how you plan to code the alarm. Show it to the teacher.
2. Get the BBC micro:bit material and begin to assemble and code the alarm.

(Tip: Use the light-sensor in the micro:bit)

Good luck!

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Analysing and designing Programmed Technological Solutions (PTS) using programming materials has been included as part of technology education in an effort to introduce programming in compulsory school. However, what appropriate teaching at this level entails from a pupil's perspective remains to be articulated. Therefore, the aim of this thesis is to contribute knowledge regarding what to address in teaching and learning technology in processes of analysing and designing PTS. The knowledge domain of PTS, in relation to technological literacy, frames the results from three phenomenographic studies that investigate the ways pupils (aged 10-14) experience PTS in the processes of analysing and designing in the context of the BBC micro:bit material and PTS from everyday life.

The results show that understanding programming concepts and how to produce code are key elements, but there are other key elements embedded in the processes, i.e. knowledge related to the dual nature of PTS and to the programming material, awareness of the relevance structures provided by the contexts in terms of experienced part-whole structure of PTS, and the use of systems thinking to see the part-whole structure. These elements are important to consider in pedagogical practice in order to promote learning with regard to PTS.

Anne-Marie Cederqvist is a teacher and researcher, whose main research interest is technology education in relation to digital technology.

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