



An exploratory study of technological knowledge when pupils are designing a programmed technological solution using BBC Micro:bit

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Abstract

Technology educators often provide activities where pupils design programmed technological solutions (PTS) with various programming materials for developing pupils' technological knowledge related to PTS and digital technology. However, few studies have investigated how pupils experience these activities. To fill this gap in knowledge, this phenomenographic study explores how pupils experience designing a PTS using BBC Micro:bit and identifies the technological knowledge these pupils need, in terms of critical aspects (i.e., aspects necessary to discern), to successfully solve a real world task—the design and coding of a burglar alarm. The data were gathered from sketches, interviews, and video-recordings of pupils aged 10 and 14. This study shows that the pupils struggled with two intertwined phenomena during the activity: the dual nature of the PTS (i.e., the structure and function) and the BBC Micro:bit material. The findings indicated that the pupils needed to understand what components to use based on their function and how to organise these components so they interacted with a code that used feedback control. That is, the pupils needed to code a conditional statement by combining blocks in the BBC Micro:bit editor. To produce working code, the pupils needed to know what the blocks represent, where to find the blocks in the editor, and how to interpret the shapes of the blocks. The results have implications for teaching technological knowledge, suggesting an importance of addressing these phenomena and critical aspects with respect to developing pupils' conceptual and procedural knowledge related to designing PTS with BBC Micro:bit.

Keywords Technology education · Technological solutions · Programming · Programming materials · BBC Micro:bit · Phenomenography

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Introduction

Technology education should provide pupils with knowledge to go beyond being uncritical consumers of digital technology and to be able to critically analyse and make well-informed decisions concerning the digital technology that surrounds them. Therefore, digital technology has become a part of the overall aim in technology education where to develop pupils' understanding of technological solutions in everyday life. The aim is bi-directional: pupils should be able to identify and analyse existing programmed technological solutions (PTS) from their structure and function and be able to design and program their own PTS (Skolverket 2017). Typically, teaching uses different programming materials such as the BBC Micro:bit to develop pupils' knowledge of concepts and processes related to PTS and programming and understanding of digital technology in general. However, previous studies (Mioduser et al. 1996; Slangen et al. 2010) show that when pupils design a PTS with programming materials such as Lego kits, they have difficulties understanding how to program in relation to the function of the components. As a result, they avoid certain functions in their PTS because they are unable to control the PTS with the programming needed, limiting their possibilities of successfully designing the intended PTS. Other studies report that pupils often have difficulties connecting programming materials with the abstract phenomena the materials represent (Cederqvist 2019; Ivarsson 2003). Even when pupils are introduced to simple block programming, semantic difficulties remain (Grover and Basu 2017). Previous studies indicate that it cannot be taken for granted that programming materials automatically develop pupils' understanding of phenomena related to PTS and programming (Cederqvist 2019; Ivarsson 2003; Kalelioglu and Gülbahar 2014). In addition, it cannot be taken for granted that technological knowledge is an automatic outcome of the design process (Svenningsson 2019). In these kind of activities, pupils need guidance from their teacher (Cederqvist 2019; Ivarsson 2003; Lye and Koh 2014; Pea 1983).

According to de Vries (2005), pupils' success in the design process is based on the extent they are able to make a fit between factors in the process such as the problem to solve, as well as the material to be used. These factors encompasses conceptual and procedural knowledge that are needed for being able to realise the intended solution. Hence, it is necessary to reflect on these factors and what phenomena they involve. However, little research has investigated the process of designing PTS with programming materials with respect to knowledge related to the phenomena involved. To organize pertinent teaching for developing pupils' knowledge in this area, it is necessary to investigate what these phenomena are and in what way pupils experience these phenomena. To this end, this study explores what phenomena are in focus and how pupils experience designing a PTS with the BBC Micro:bit. In addition, this study identifies the technological knowledge these pupils will need in terms of critical aspects (i.e., aspects of phenomena necessary to discern) to be successful. That is, this study identifies how teachers can help pupils' understand PTS when using programming material such as BBC Micro:bit.

Technology education and PTS

Every citizen needs some technological literacy to live in our society. Technological literacy is the ability to 'understand nature of technology, have a hands-on capability and capacity to interact with technological artefacts, and [...] be able to think critically about

issues relating to technology' (Collier-Reed 2008 p. 24). Ingerman and Collier-Reed (2011) suggest that technological literacy is an aspect of learning and living as technological literacy is a characteristic of how individuals experience and act with respect to technological artefacts and processes. Thus, technological literacy encompasses both education and everyday life. Today, technological literacy primarily refers to the technological knowledge needed to understand, to make decisions, and to act with respect to digital technology. That is, technological knowledge refers to the digital competence citizens need (Ferrari 2012), knowledge that has become part of almost every country's educational curriculum. Hence, technology education should provide pupils with the technological skills and knowledge to understand digital technology that allows them to live in today's digital society.

Technological knowledge when designing a PTS

In many countries, the goals for technology education are technological literacy (Nia and de Vries 2016), where also digital competence is integrated as a goal. Achieving these goals is the basis for pupils' ability to understand and use digital technology in everyday life. Developing the ability to understand and use digital technology is closely intertwined with pupils' abilities to analyse and design PTS, prerequisites for understanding how PTS and more complex digital technology affect everyday life (Skolverket 2017).

Technological work such as evaluating technological problems and designing technological solutions requires specific technological skills and knowledge. These technological skills and knowledge may be defined as conceptual and procedural knowledge (see Anderson et al. 2001; McCormick 1997). Anderson et al. (2001) suggest conceptual knowledge includes schemas, models, and theories that are representing how parts of information or content elements are interrelated, and function together, to organize particular subject matter. Further, conceptual knowledge is the knowledge needed to grasp and link technological concepts in diverse contexts (McCormick 1997). Procedural knowledge is the practical knowledge needed to apply conceptual knowledge to specific technological tasks such as making a model or planning a project (i.e., knowledge of methods, algorithms, techniques), as well as knowing when to use them (Anderson et al. 2001). McCormick (2004) also suggests a third type of technological knowledge—qualitative knowledge. Qualitative knowledge is specific technological knowledge related to the context of a specific problem. That is, qualitative knowledge refers to the technological knowledge of interrelated concepts and processes necessary for a specific context.

The ability to analyse or design a PTS is based on understanding the dual nature of PTS—the functional and the structural (de Vries 2005). The understanding of the dual nature involves four types of knowledge related to the PTS (de Vries 2006): knowledge of physical nature such as properties of the solution; knowledge of the functional nature such as functions that will be fulfilled; knowledge of the relation between the physical 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. A way to facilitate the understanding of the dual nature is to approach PTS as a technological system. This approach is based on three overall skills: understanding the components of the system; understanding how the components interact; and understanding the system as a whole (Booth Sweeney and Serman 2007). Representations of technological systems may be seen as models or cognitive maps of reality (Ropohl, 1999) where the characteristics of the design process and the back and forth between the structural and functional aspects (de Vries 2019) are made more explicit.

When solving a problem that involves the design of a PTS using programming material, pupils are required to use qualitative technological knowledge that encompasses both conceptual and procedural knowledge. However, the qualitative technological knowledge that will be necessary for a successful design process depends on factors such as the technological problem to be solved and the programming material to be used. These factors include the knowledge of the phenomena involved, of the material and processes needed, and of the way the material and processes fit (de Vries 2005). For example, Barak and Zadok (2009), in a description of the programming material Lego Mindstorms, describe the qualitative knowledge needed to solve a technological problem as the understanding of when and how to use feedback control or open-loop control or the ability to identify factors that influence a mechanical structure.

Programming materials for developing technological knowledge

Programming materials such as the BBC Micro:bit, Lego Mindstorms, or Arduino are used to concretize and facilitate pupils' understanding of concepts and processes related to skills and knowledge associated with programming. Additionally, in technology education, these kinds of programming materials, also called Direct Manipulation Environment (DME), are considered a good point of departure for developing technological knowledge. DME materials create opportunities to develop knowledge about technological concepts related to physics such as speed, acceleration, forces, and balance (Krumholtz 1998) and develop procedural knowledge related to programming and to the problem-solving process of designing a PTS (Barak and Zadok 2009).

However, previous studies indicate that pupils have difficulties making connections between the programming materials and the abstract phenomena the materials represent. In a study by Cederqvist (2019), pupils' understandings of PTS were investigated. The pupils were presented to PTS in the BBC Micro:bit context, and to PTS in the everyday context. The results show that even if the pupils were taught with different programming materials such as the BBC Micro:bit and Lego Mindstorms between one or two years, pupils' understanding of PTS varied with respect to the two contexts. In addition, Cederqvist's study revealed that the pupils approached the two contexts differently, a finding that indicates the use of programming materials does not necessarily develop pupils' understanding of PTS in the everyday context. In another study, Ivarsson (2003), investigating how pupils use the programming material Lego Dacta to solve a problem involving recursion, found that pupils were able to solve advanced problems with the support of the visual and interactive aspects of the programming material. However, Ivarsson also found that the pupils did not gain a deeper conceptual understanding that could help them beyond the specific problem solving activity, so they were unable to solve similar problems. Today, in problem solving activities that include programming, pupils often use block programming to make it syntactically easier to program. However, block programming still presents conceptual difficulties with respect to understanding what the blocks represent and how to use them when building code that includes variables, conditions, and loops (Grover and Basu 2017).

A study by Slangen et al. (2010) found that pupils aged 10–12 designing and programming a robot using Lego Mindstorms relied on system thinking to understand the parts of the system and functional relationships such as feedback control, skills that require the analysis of real world conditions to solve technological solutions. This skill also requires logical reasoning and understanding of concepts used in programming such as 'if', 'else', and 'then'. In addition, Slangen et al. found that pupils needed help programming

conditional statements and that several pupils chose to exclude feedback control in their PTS. In another study, Mioduser et al. (1996) examined how 6th grade pupils understood the control process and the components of an automatic controlled door they designed and built using Lego, motors, and sensors. They found that the pupils had difficulties understanding the entire chain of control functions in the system and how the components communicate with each other. That is, Mioduser et al. concluded that the pupils did not understand how the components worked, how each component affected the whole system, and how the flow of information was controlled by feedback.

Previous studies (Cederqvist 2019; Ivarsson 2003; Lye and Koh 2014; Pea 1983) found that pupils need guidance from a teacher to discern what the programming materials represent and to understand the technological knowledge involved. Furthermore, Barak and Zadok (2009) argue that pupils lack the technological knowledge required for designing a PTS with programming material such as Lego Mindstorms and that pupils often do not see the relation between the activity and the subject matter. Clearly, teachers, researchers and developers of educational software and hardware need to better understand the process of designing a PTS with a programming material so as to gain more in-depth knowledge about how best to use these materials when instructing pupils for developing technological knowledge. Therefore, this study explores what technological knowledge pupils need when designing a PTS with the BBC Micro:bit. The findings in this study should help teachers design lesson plans around the conceptual and procedural knowledge pupils need to master when designing a PTS with programming material such as the BBC Micro:bit.

Methodology and research design

To gain in-sight in how pupils experience designing a PTS with the BBC Micro:bit material, this study was carried out with a phenomenographic approach. Data consist of sketches drawn by pupils, interviews and video-recordings while they were designing and programming a burglar alarm using BBC Micro:bit.

The phenomenographic approach

In phenomenography, knowledge is described as a way of understanding or experiencing a phenomenon. When something is learned, learners become aware of a previously undiscerned aspect of a phenomenon, and understanding or experiencing the phenomenon in a new way (Marton and Booth 1997). By investigating how a phenomenon can be understood or experienced, the variation in understanding or experiencing the phenomenon can be identified. These variations can be referred to either as structural aspects or referential aspects. For Marton and Booth, structural aspects refer to the parts of a phenomenon, the relationships between these parts, and the relationships between the parts and the whole of the phenomenon and referential aspects refer to the discerned meaning of the phenomenon, which is closely intertwined with the structural aspects. When a phenomenon is understood or experienced, the structural and referential aspects co-occur in the learner's awareness based on what structural and referential aspects the learner discerns.

Thus, in the phenomenographic analysis, the variation in experiencing a phenomenon is examined based on the discerned structural and referential aspects, where pupils' ways of understanding or experiencing are distinct hierarchical categories logically related to each other according to complexity (Marton and Booth 1997). These distinct categories constitute a category system, the outcome space, which is the result of the phenomenographic

study. In the outcome space, critical aspects based on differences between the categories can be identified that enable learning (Marton and Booth 1997). Discerning these critical aspects is necessary for understanding or experiencing the phenomenon in a more powerful way.

Typically, phenomenographic studies investigate how individuals understand or experience a phenomenon using semi-structured interviews by asking questions directed towards the phenomenon. However, these studies may also investigate how individuals understand or experience a phenomenon by analysing actions or skills (e.g., when carrying out a movement) (Nyberg and Carlgren 2015) or a specific task. Björkholm (2015) argues that technological knowledge is expressed both in words and actions, where cognitive and physical processes are intertwined; therefore, it is important to analyse both actions and verbal expressions. In the present study, the aim is to explore what phenomena are in focus when pupils are designing a PTS with the BBC Micro:bit and to identify the necessary technological knowledge in terms of critical aspects. Therefore, the analysis is based on what pupils express both verbally and in their actions during the design process as well as in semi-structured interviews after they have designed the PTS.

The data collection

In this study, eight pupils from grade 4 and six pupils from grade 8 participated on two separate occasions. Before the study, the pupils' classroom teacher had provided a series of lessons that introduced the BBC Micro:bit material. These lessons were based on a paper tutorial that included instructions on how the material is structured, how to use the material, and several programming tasks. The pupils in grade 4 were given five lessons lasting approximately 40–50 min per lesson. The pupils in grade 8 were given three lessons lasting approximately 80 min per lesson.

In the study, the researcher introduced a task to the pupils where they were supposed to use BBC Micro:bit to design and program a burglar alarm. Working in pairs, the pupils discussed and sketched a solution. For inspiration, they had a sheet showing different blocks that can be used in the Micro:bit editor. Next, the pupils had to realise their plans using the BBC Micro:bit material, and programming the code on an iPad or a computer. The grade 4 pupils used computers and the grade 8 pupils used iPads. While they worked, the pupils were video-recorded using a Go-Pro camera attached to the ceiling above each pair of pupils. When the grade 8 pupils were coding, screen capture software recorded their activity on the iPad. Unfortunately, this type of data collection was not possible on the computers due to restrained access to the software, so the grade 4 pupils' coding activities were not recorded in this manner. However, the activity on the computer screen was captured by the Go-Pro cameras. A microphone was placed in front of each pair of pupils to capture their utterances while working on the task (Fig. 1). During the activity and in a following interview, the pairs of pupils were asked questions about their process of designing the PTS.

The BBC Micro:bit material

The BBC Micro:bit consists of a small programmable microcontroller that includes a LED display, a compass, an accelerometer, programmable buttons, light and temperature sensors, and a Bluetooth connection to other Micro:bits and other devices. Through its five Input/Output rings, the microcontroller may also be connected using crocodile clips to

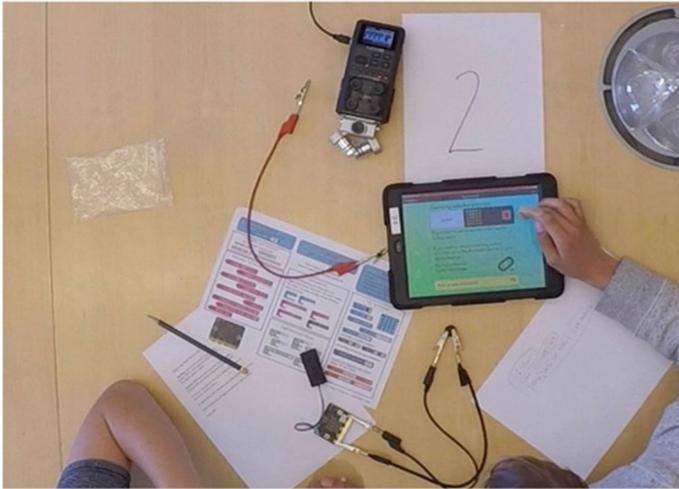


Fig. 1 Pupils working with task

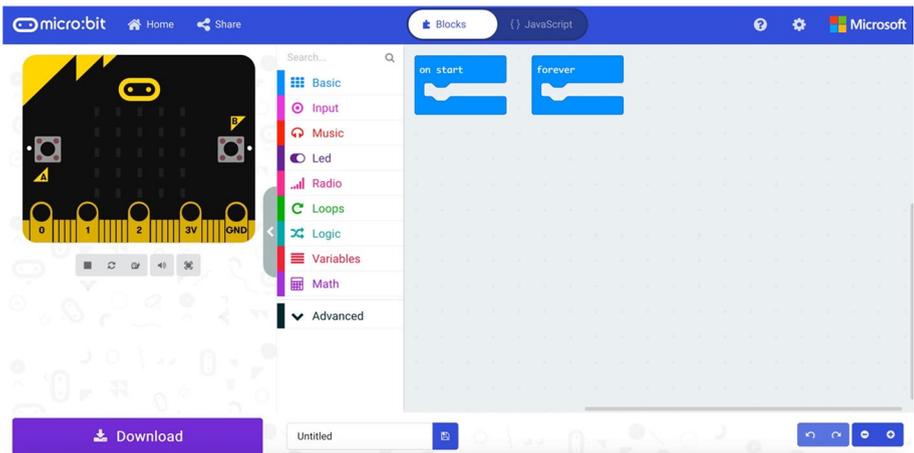


Fig. 2 The user interface of the Microsoft MakeCode Micro:bit editor <https://makecode.microbit.org/#editor>

external components such as a motor, a sensor, or a speaker.¹ The BBC Micro:bit can be programmed in both a text-based editor and a block-based editor. In this study, the block-based Microsoft MakeCode Micro:bit editor was used for both the computers and the iPads. In the block-based editor, the pupils build their code by snapping together different

¹ Make it Digital <https://www.bbc.co.uk/programmes/articles/4hVG2Br1WILKcmw8nSm9WnQ/the-bbc-micro-bit>.

blocks for controlling the function of the PTS they have designed. Below is the user interface of the editor illustrated (Fig. 2).

In the middle of Fig. 2, tabs identify where to find available blocks that can be dragged into the grey area to the right, where the pupils build their code. The code can then be tested with the simulator to the left. To download the code to the BBC Micro:bit, the pupils click on the download button. The BBC Micro:bit can be used with motors, sensors, and speakers to design a wide extent of technological solutions that can be controlled by code programmed in the editor. Thus, the BBC Micro:bit material provides opportunities for developing pupils' understanding of PTS and therefore improve their ability to design and program a PTS.

The analysis

With a phenomenographic approach, the sketches, the transcribed interviews, and the video-recordings of the pupils were analysed to discern what are in focus and experienced differently in the process of designing the PTS. First, the sketches were analysed by identifying differences in representations of solutions in the sketches. From this, preliminary categories could be created that represented the variation in the sketches. Then, the transcriptions of the interviews were analysed. The transcribed material was read through several times to identify passages that show differences in experiences of designing a PTS. Excerpts were selected and placed into preliminary categories based on their differences. Next, the video recordings were analysed to find sequences in the material that showed differences in pupils' experiences. These sequences were transcribed verbatim along with descriptions of the pupils' actions. Then, these sequences were placed into preliminary categories based on their content. This initial part of the analysis resulted in a set of preliminary categories based on the different sources of data. This part of the analysis revealed that pupils are involved in two intertwined phenomena during the process: the dual nature of the PTS and the BBC Micro:bit material.

The two phenomena were analysed separately by taking the phenomenographic approach to gain in-depth knowledge of how the pupils are experiencing the two phenomena. First, the preliminary categories from the different sources of data were merged into common categories regarding each of the phenomena based on similarities and differences. This resulted in preliminarily outcome spaces: one for the dual nature of the PTS and one for the BBC Micro:bit material. Both these outcome spaces were then further analysed from the structural and referential aspects that characterize the understanding in each category. The two outcome spaces were then tested on excerpts of transcribed data and adjusted. Based on the differences between the categories in each outcome space, the critical aspects were then identified. In relation to each outcome space, excerpts were then selected that represent the qualitatively different categories although logically and structurally related to increasing complexity. The outcome spaces were then explored in relation to each other and in what way the process of designing a PTS depends on understanding the phenomena.

Ethical issues

To investigate pupils' experience when designing a PTS, the pupils were studied by interviewing and video-recording them as well as collecting their sketches. Thus, there were ethical issues to consider before, during, and after the data collection. To carry out the

study, consent from pupils, parents, guardians, teachers, and principals was obtained. They were given information about the purpose of the study, how data would be collected, and in what way the pupils would participate. They were also informed about the confidentiality and self-determination regarding participation, and the possibility of withdrawing from the study at any time, as well as how the collected data would be handled and stored. In the reported data, the pupils have been anonymized and images of the pupils have been obscured to prevent their identification.

Limitations of the study

The study is conducted with a phenomenographic approach. The knowledge claim is based on the qualitative differences in pupils' ways of experiencing the phenomena involved in the process when designing a PTS with the BBC Micro:bit. The study includes 14 pupils, a sample size insufficient for quantitative analysis and statistical generalisation. However, the large amount of qualitative data, consisting of pupils' sketches, video-recordings, and semi-structured interviews, may be seen as rich data that can be qualitatively analysed. Hence, the results provide an in-depth insight into how pupils experience the phenomena involved, which may not be possible from studies with less qualitative data but more participants. A limitation of the study may lie in the fact that the series of lessons that pupils were given before by their teachers have not been studied. In order to understand the ways pupils are carrying out a learning task, it would be necessary to take into account previous teaching given by their teacher. However, phenomenography is not used to describe the outcome of previous teaching. It is used to form collective categories of description, based on pupils' different understanding or experience of phenomena, decontextualized from their original framework. That is, the pupils are seen as bearers of different ways of understanding or experiencing phenomena, which may be based on previous teaching, but this history is stripped away in the processing of data, and the categories of description will in the end only retain meaning and structure of the different ways of understanding phenomena (Marton and Booth 1997). Another limitation of the study may be that the result is seen as related to a specific context (i.e., the technological task) and this group of pupils. However, as the result may be applicable to similar contexts, the relevance of the study should be evaluated based on specific contexts rather than generally applied.

Results

The results are reported in two parts based on the analysis. First, the two outcome spaces regarding the dual nature of the PTS and the BBC Micro:bit material are individually described. Excerpts are used to illustrate how data were interpreted. Each outcome space is summarised according to the structural and referential aspects for each category and the distinct differences between the categories in terms of critical aspects. Second, the relation between the outcome spaces is described.

Outcome space: how pupils experience the dual nature of PTS

The analysis of how pupils experience the dual nature of PTS resulted in three categories that are logically related and qualitatively distinct from each other:

1. The black box approach
2. The white box approach
3. The feedback system approach

In the black box approach, the least powerful approach, the structural parts of the PTS are discerned as black boxes that interact with each other and in some way affect the function of the PTS. The white box approach implies that the black boxes are unpacked such that a broader understanding of both the structural and functional nature of the phenomenon is achieved. In the feedback system approach, the pupils discern the PTS as a system based on structural parts such as the use of specific components, how these interact based on feedback control, and how these form a whole system that performs a function.

The black box approach

In this category, pupils' descriptions of what the code and its structure represent is fragmentary as they can only vaguely describe the relation of the components and the function of the PTS. They describe what components to use and have an idea of how to connect the components, but their understanding of how the components work and how they are organised with respect to their function is vague. The pupils' unclear understanding of what the code represents and their vague understanding of how the components work together probably explains why they lack an understanding of how information flows and is generated by the interaction between the code and the structure of components. However, the pupils are able to describe that the code and the components interact in some way and that this interaction affects the function of the PTS.

In the excerpt below, the pupils describe the components they use in their PTS and how to connect them. However, the description is vague as it lacks specificity concerning the organization of components and how these components work to fulfil the function of the PTS. For example, they set the light level to 125 without understanding what this means, and they can only vaguely describe the light sensor. Thus, the parts of the PTS are discerned as black boxes; that is, the pupils understand that the change in light level makes something happen based on an interaction between the code and the components, which affect the function, but do not understand how this controls the function of their PTS. They describe the Micro:bit as the 'brain' and the components as the 'body' without involving the logic in the code and how the components are structured to generate a flow as they probably do not fully discerned these aspects.

- Pupil 4 We needed to connect these then [shows the wires] or Peter connected it into that one [the Micro:bit] since he asked if that was ok, and then we connected the other part of these wires into a little speaker, and then there is this wire... that goes into the computer itself or yes that makes everything come true, and yes then when we have the right stuff the alarm will work [...]
- Interviewer How does this alarm start?
- Pupil 3 It's when it comes to a certain light level, at 125, we have set it to, I don't understand that number but [...]
- Interviewer What happens then?
- Pupils 3 Then it starts to beep
- Interviewer [...] Where does it start, would you say?

- Pupil 3 I would guess that it is these plates or something [shows the display on the Micro:bit]
- Interviewer And then, what happens?
- Pupil 3 Then it turns on the sound [...]
- Interviewer Why is the sound turned on? At that light-level?
- Pupil 3 We have program [...] because we have programmed that or what?
- Pupil 4 Yeah
- Pupil 3 So that one is the master brain [the Micro:bit] and this is [...] as on us, this is the brain [the Micro:bit] and these are the body parts [components] which that one controls to do things

The white box approach

The white box approach refers to that pupils are able to describe what the code and its structure represents. In addition, the white box approach reflects an awareness the pupils have of what components to use, how the components can be organised in the PTS, and how these components interact with the code to generate a flow that controls the function of the PTS. However, the excerpts indicate that the pupils are unaware of how the components work, what their specific functions are, and that the generated flow is information based on feedback control.

The pupils in the excerpt below describe what the code and its structure represent and relate this to the components they use in the PTS, which can be seen when they describe how they have connected the components. In addition, the pupils describe how the code in the Micro:bit causes sound to come out of the speaker, an understanding that indicates an awareness of an interaction between the logic in the code and the organization of components. Initially, the pupils believed the code causes electricity to be sent between the components. However, their description that the alarm starts because it has 'learned' to do this from the code indicates that they do not fully have grasp the interaction between what is written in the code and the function of the components. That is, they do not understand that the flow is information that is based on the feedback control function in the PTS.

- Pupil 8 I think it's like this: the computer sends it to the Micro:bit and the Micro:bit sends it to the speaker, through these wires [show the wires]
- Interviewer What is sent?
- Pupil 8 Mm...electricity? [laughs] [...]
- Interviewer And how does the alarm start?
- Pupil 7 [...] we have written in the code that if it gets brighter, then the alarm starts to sound since that is then inside the Micro:bit, and then it continues to the speaker
- Interviewer How does it [the alarm] know when to start?
- Pupil 7 Eh [...] because when it gets brighter, it starts
- Pupil 8 It has, like, learnt it [...]
- Pupil 7 We have written it [...]
- Interviewer And what happens then?
- Pupil 7 The Micro:bit is connected to the speaker, so then [...] since we have connected the wires, the speaker does what we have written there [pointing at the code] [...]
- Interviewer Can you describe for me how you have assembled this alarm?

- Pupil 7 [...] First, we have connected the computer, or the Micro:bit to the computer, so these two are kind of connected, and we have programmed to the Micro:bit [shows the wire between the computer and the Micro:bit]. Then, we have connected from the Micro:bit, since this [pointing at the code] is somehow inside the Micro:bit. So then we have connected it to the speaker so that the speaker does what's [...] what's in the Micro:bit [...]
- Interviewer [...] and the light level that is written here, what part does it belong to?
- Pupil 7 Eh [...] that one, the Micro:bit
- Interviewer Is it the whole Micro:bit, or some part of it?
- Pupil 7 Maybe the lamps [...] maybe?
- Interviewer These lamps? [points at the Micro:bit] How do they work?
- Pupil 7 Maybe they are able to sense light [...]
- Interviewer [...] and this, START MELODY, you have chosen DADADUM REPEATING ONCE, what part does this belong to?
- Pupil 8 It sounds like that, yeah, it sounds in that way [laughs] and when we connect them the speaker plays a sound when it gets brighter

The feedback system approach

The feedback system approach differs from category two in the way that the pupils understand the code and its structure, including the feedback control. The excerpts also show that the pupils see not only how the components can be organised to solve their task but also how the components work and function in the PTS. The excerpts indicate that the pupils understand the logic in the code in terms of feedback control, and how the code interact with the organisation of components where the interaction generates a flow of information that controls their alarm.

In the excerpt below, the pupils describe in detail the components they use and how they work as well as how they interact based on how they are organised, and based on the logic in the code. Furthermore, they describe how the light sensor and feedback controls the function in their PTS. That is, the pupils understand that their code sent to the Micro:bit causes the alarm sound to come out of the speaker when the light level changes. This understanding indicates an awareness that the interaction generates a flow of information controlled by feedback.

- Pupil 12 [...] the battery in itself is the only power source with different charged particles, which is passing through the wires of may be copper or some good conductive material, to this one [the Micro:bit] which is like a mini-computer, almost, or to what we send the code to. And this [the Micro:bit] also has something conductive material inside itself, and the speaker takes these electrical signals and transform them into sound waves. Thus, it makes it to air by a vibrating membrane
- Interviewer This Micro:bit, what function does it have in this alarm?
- Pupil 11 [...] it simply does what we have told it to do, we program it, that's what it [...] it is used for [...]
- Pupil 12 And here [pointing at the lamps/light sensor at the Micro:bit] is what it first should sense, it will measure the light then and if it gets [...] exceeds this [shows the LIGHT LEVEL in the code] then it sends [...] or sends [...] then it should send a certain electricity to the speaker [...]

- Interviewer If you try to connect what's written in the code with these parts, could you describe for me what you have intended to do?
- Pupil 12 Well, when the system starts then eh [...] then this one senses the light [...] that sensor inside these [points at the diodes on the Micro:bit], which senses the sound eh [...] the light, begins to measure and then if it's higher than this value, which we shifted between, if it's higher than 100, then it sends electrical or it sends electricity through this [show the wire] to the speaker, which starts to sound
- Interviewer You say that it sends electricity, but how does the speaker know that it will play this melody that you have or that tone that you have decided here [points at the code]?
- Pupil 11 We have programmed it to do that
- Pupil 12 [...] But it's like this one [the Micro:bit] yeah it sends signals to that one [the speaker] what to play [...]
- Interviewer You say signal, what is a signal?
- Pupil 12 Well, it sends electrical [...]
- Pupil 11 It sends [...] it's like sending a message to someone's cell phone, it is what it does in there [in the alarm]

Summary of the outcome space: how pupils experience the dual nature of PTS

The variations in pupils' way of experiencing or understanding the dual nature of PTS are related to what aspects of the phenomenon the pupils have discerned. These aspects can either be referred to as structural aspects (i.e., how the whole of a phenomenon is discerned in relation to its parts and how the parts are discerned in relation to each other and to the whole) or be referred to as referential aspects (i.e., the discerned meaning of the phenomenon) (Marton and Booth 1997). Thus, the analysis of the structural and referential aspects was used to categorise the outcome space (Table 1). The analysis of how pupils experience the dual nature of the PTS shows qualitative differences in relation to the discerned structural aspects (i.e., the logic and the organisation) and in relation to the discerned referential aspects (i.e., the function). The pupils in category 1 can discern what components to use and how to connect them. They also can discern that there is an interaction between the components and the logic in the code and how this affects the function of the PTS. However, these pupils approach the code and the components as black boxes. They have a fragmentary understanding of what the code represents. This fragmented understanding and their lack of understanding of how the components work and how they can be organised make it difficult for the pupils to understand how to control the function within the PTS. The pupils in category 2 have unpacked the black boxes. They can describe what the code and its structure represent and can organize the components, which generate a flow that control the function. However, these pupils do not know how the components work in the PTS and how the feedback control generates a flow of information that makes it possible to control the intended function of the PTS. Pupils in category 3, however, understand how the code and components work together to function as a feedback system that produces the desired outcome.

Within the outcome space, the distinct differences between the categories were identified, the critical aspects necessary to discern for experiencing the dual nature of PTS in a more powerful way. The following is a summary of the critical aspects necessary for pupils to discern:

Table 1 Outcome space—how pupils experience the dual nature of the PTS

The dual nature of the PTS Category	Structural aspects		Referential aspect Function
	Logic	Organisation	
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 affect 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

Fig. 3 The non-functional code

- The logic in the code in terms of feedback control in the PTS.
- How the components work and how they can be organised in the PTS.
- How the interaction between the code and the components based on feedback control generate a flow of information that controls the function of the PTS.

Outcome space: how pupils experience the BBC Micro:bit material

The analysis of how pupils experience the BBC Micro:bit material resulted in three categories that are logically related and qualitatively distinct from each other:

1. The novice user approach.
2. The intermediate user approach.
3. The proficient user approach.

The results show that pupils approach the BBC Micro:bit material differently. The novice user approach describes how the pupils puzzle the code together randomly, since they have a limited understanding of what the blocks represent as well as how to combine them to make functional code. In the intermediate user approach, the code is brought together based on the shape of the blocks together with the understanding of what the blocks represent in terms of real world conditions. In the proficient user approach, the pupils navigate confidently in the editor and find the necessary blocks to combine into a functional code based on what these represent in terms of programming concepts.

Novice user approach

The novice user approach describes pupils who have a limited understanding of what the blocks represent, and how the shape of the blocks should be interpreted. These pupils randomly search for blocks in the Micro:bit editor. In addition, these pupils have not yet discerned the relation between the combination of blocks and the intended control function in the PTS as they do not see what the blocks represent in terms of real world conditions. Their limited understanding of what the blocks represent and how their shape should be interpreted makes it difficult for them to combine the blocks to control the PTS.

The pupils in the excerpt below have an idea of how to start the alarm by using the movement of the cabinet door when it is opened as well as the difference in light level when the cabinet door is opened. However, the pupils search randomly for suitable blocks to use and therefore produce non-functional code (Fig. 3).

- Pupil 1 Go for VARIABLES and check out what it is
 Pupil 2 INPUT is this one: SET UP [...]
 Pupil 1 INPUT?

- Pupil 2 Yes and then if you go down a bit
- Pupil 1 We take ON SHAKE, that's what we need [drags the block into the code]
- Pupil 2 Eh ON SHAKE SET BRIGHTNESS
- Pupil 1 Wait a minute, we will have a sound or how should the alarm be? LED, LOOPAR, LOGIC? What was it that we were supposed to have?
- Pupil 2 Eh this: SET BRIGHTNESS [points at the sheet with different blocks] when shaking it should set [...]
- Pupil 1 Brightness, it should be on [...] where should it be on?
- Pupil 2 Eh... wait check that one
- Pupil 1 ADVANCED? [clicks on the ADVANCED tab]
- Pupil 2 Yes [...] no
- Pupil 1 Maybe we can use CONTROL?
- Pupil 2 It can run in the background
- Pupil 1 I think it's a little too advanced [the pupils search further]
- Pupil 2 Button for setting brightness [the pupils find the block SET BRIGHTNESS that they want to use]
- Pupil 1 And then we put that one there yes [drags the block into the code]
- Pupil 2 Put it there
- Pupil 1 That's it
- Pupil 2 Wait, set the brightness when it shakes, set it to like 1000

[Pupil 1 changes the level of brightness in the code and tests the code in the simulator, but nothing happens]

- Pupil 2 Is there anything wrong in it [the code]?

The excerpt shows that the pupils have a limited understanding of what the blocks represent, which in the end makes it difficult to combine the blocks in a way that controls the PTS as intended. They seem unable to connect the control function to the real world conditions in terms of how to choose and organise the blocks. When their test of the alarm in the editor does not work, they cannot see that the combination of blocks is implausible although they do understand that something is wrong.

Intermediate user approach

The intermediate user approach describes pupils who understand what the blocks represent in terms of real world conditions, what the different shapes of the blocks mean, and that they can use this understanding to search for blocks. However, they do not understand the organization of blocks in the editor, so they search randomly between the tabs to find suitable blocks. In addition, these pupils understand they need a control function in the code, but they are unable to combine the blocks to produce the desired outcome.

The pupils in the excerpt below have an idea of designing an alarm with a control function where the sensor registers the difference in light level when the cabinet door is opened, resulting in the activation of the alarm. They have begun to search for blocks to use in their code and have found the block ON SHAKE and the block LIGHT LEVEL, which they try to combine. They also understand that they need to add a block for sound such as the PLAY TONE or START MELODY. The excerpt shows that the pupils understand what the blocks represent in terms of real world conditions such as the shaking and the change in light level when the cabinet door opens. However, the two blocks cannot be combined. However, the

Fig. 4 Pupils discern the shape of the blocks



Fig. 5 The pupils discern the shape of the blocks

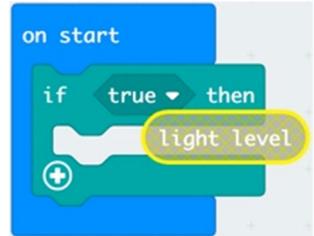


Fig. 6 The pupils are able to combine the blocks into a control function



pupils seem to understand that the shape of the block matters (Fig. 4), knowledge they use to search the editor for another block. The excerpt indicates that pupils have a vague understanding of how to combine the blocks in a way that fits their idea of the control function in the PTS. This incomplete understanding is probably based on not understanding the necessary programming concepts generally and the function of the blocks specifically.

Pupil 9 Which one were we supposed to start with, was it INPUT or was it [...]

Pupil 10 Eh [...] ON [...] SHAKE

Pupil 9 [Search among the tabs in the Micro:bit editor] ON [...] SHAKE [...] there we have it [drags the block into the code]

Pupil 10 Mm

Pupil 9 What was it that we should have then?

Pupil 10 PLAY TONE

Pupil 9 But LIGHT LEVEL?

Pupil 10 Or START MELODY

Pupil 9 LIGHT LEVEL I'll just put it there [tries to drag the LIGHT LEVEL block into the ON SHAKE block]

Pupil 9 [...] it is not possible to put in LIGHT LEVEL

Pupil 10 Huh?

Pupil 9 No, you could not put LIGHT LEVEL in this block

- Pupil 10 Wait you can't just put it in [...] what does it say here? [clicks on the drop-down in the ON SHAKE block and various options appear]. What is it when you open it [the cabinet door]?
- Pupil 9 I don't think you can use this. Is there any other block that is similar?
- Pupil 10 It's such a BASIC block [pointing at the sheet with different blocks]
- [The pupils are looking through the BASIC tab in Micro:bit editor]
- Pupil 9 Mm, it shouldn't be ON START [...]
- [The pupils laugh]
- Pupil 9 [...]but how to start then?
- Pupil 10 Is it [...] can you do the opposite? No
- Pupil 9 What are you thinking about?
- Pupil 10 So [...] no this won't work eh [...]

Proficient user approach

The proficient user approach describes pupils who understand how a control function can be combined in terms of blocks. That is, these pupils understand what the blocks represent in terms of programming concepts, what the shapes of the blocks represent, and use this information to search for blocks that can be combined. Their search for blocks is more confident compared with the pupils who randomly search, indicating that these pupils understand how the blocks are organised in the editor.

The pupils below have sketched a control function including a conditional statement (IF/THEN) based on real word conditions: if the sensor registers a change in light level (i.e., the cabinet door is open), then the alarm will sound. The excerpt shows that they can navigate confidently and purposely in the editor when searching for blocks and that they have discerned what the blocks represent in terms of programming concepts. They encounter a problem when the LIGHT LEVEL block does not fit into the IF/THEN block (Fig. 5), but they discern that the shape of the block is important and use this knowledge to solve the problem by finding the COMPARISON block, which fits with the LIGHT LEVEL block (Fig. 6).

- Pupil 12 Then you take ON START
- Pupil 11 ON START IF LIGHT LEVEL [...]
- Pupil 12 Then you take IF in LOGIC or LOOPS [...]
- Pupil 11 At LOOPS? [opens the LOOPS tab]
- Pupil 12 No at LOGIC
- Pupil 11 LOGIC
- Pupil 12 IF[...]we take that one and put it there [pointing at the ON START block], and then we take [...] then we have to go to SENSOR IN [...]
- Pupil 11 SENSOR wait [...]
- Pupil 12 I think it is that one [pointing at the INPUT tab] see if there is anyone called LIGHT LEVEL
- Pupil 11 LIGHT LEVEL [Opens the INPUT tab]
- Pupil 12 There, there it is
- Pupil 11 I did [...] it doesn't fit [...]

- Pupil 12 No not there, can I try? [Tries to insert LIGHT LEVEL into the IF/THEN block but it doesn't fit]
- Pupil 12 I think we have made something wrong. I think we should find another block. We try with the LIGHT LEVEL again. [...]
- Pupil 12 ON START [...]. [Drags the LIGHT LEVEL block over the ON START block]
- Pupil 11 But it is still [...] it should only fit with such like these? [Shows blocks at the sheet with different blocks]
- Pupil 12 No that one [LIGHT LEVEL] will not fit with those. It should fit in like [...]
- Pupil 11 Would it fit in those kinds? Because if it doesn't, then it is totally worthless to focus on that
- Pupil 12 Then I take this one. [Drags out a COMPARISON block and inserts the LIGHT LEVEL block into it]
- Pupil 11 Do you see, there it fits! [...]
- Pupil 12 If light level is equal to ten [IF LIGHT LEVEL = 10] [...] wait this might work, if light level is equal, [...]. I don't know what light level to use, but then we take IF LIGHT LEVEL [...] wait take that one
- Pupil 11 Yeah
- Pupil 12 [...] where do we find PLAY TONE?
- Pupil 11 There, I think we find it at MUSIC
- Pupil 12 PLAY TONE [...]
- Pupil 11 I think we may have come up with something

Although the pupils still have some work to do, the excerpt indicates that the pupils understand what the blocks represent and how they are organised in the editor. This knowledge will help them combine the blocks in a way that corresponds to their idea of the control function.

Summary of the outcome space: how pupils experience the BBC Micro:bit material

The variations in pupils' way of experiencing the BBC Micro:bit material are related to what aspects of the phenomenon the pupils have discerned, which can either be referred to structural aspects or be referred to referential aspects (Marton and Booth 1997). Thus, the analysis of the structural and referential aspects was used to categorise the outcome space (Table 2). The analysis of how pupils experience the BBC Micro:bit material shows qualitative differences in relation to the discerned structural aspects (i.e., the logic and the organisation) and in relation to the discerned referential aspect (i.e., the function). The pupils in category 1 have a limited understanding of what the blocks in the Micro:bit editor represent, what the shapes of the blocks represent, and how the editor is organised. This limited understanding makes it difficult for them to find suitable blocks as they randomly search for blocks to piece together. In this category, pupils do not have a clear understanding of how the combination of blocks is related to the control function in the PTS. Unlike the pupils in category 1, the pupils in category 2 are able to discern what the blocks represent in relation to real world conditions as well as what the shapes of the block represent when organising the code. In addition, the pupils in category 2 understand they need a control function in the code, although they are unable to combine this understanding in terms of their manipulation of blocks. Pupils in category 3, however, can combine the intended control function in terms of blocks as they seem to understand what the blocks represent in

Table 2 Outcome space—how pupils experience the BBC Micro:bit material

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 block.	Discern the need of 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		

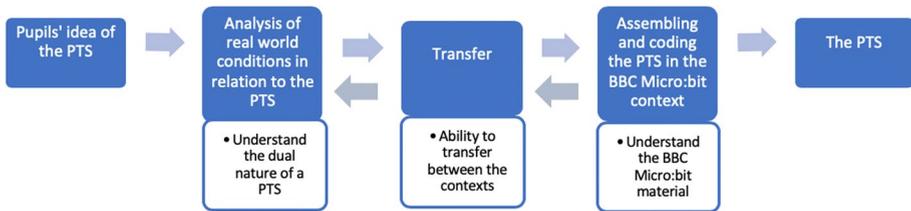


Fig. 7 The process of designing a PTS and the relation between the two phenomena

terms of programming concepts. These pupils are also able to navigate in the editor to find suitable blocks and to solve problems that occur during the process.

Within the outcome space, the distinct differences between the categories were identified, the critical aspects necessary to discern for experiencing the BBC Micro:bit material in a more powerful way. The following is a summary of the critical aspects necessary for pupils to discern:

- What the blocks represent in terms of real world conditions as well as programming concepts.
- The shape of the blocks and how the blocks are organised in the editor.
- The need of a control function in the code and how this can be combined in terms of blocks to control the function of the PTS.

The two outcome spaces in relation to each other during the process

The two outcome spaces, based on the two phenomena, show that the phenomena are closely intertwined and interdependent. In the process (Fig. 7), pupils' ideas of a PTS based on real world conditions initially needs to be analysed in relation to the dual nature of the PTS (i.e., the structure and function). This encompasses knowledge of what components to use based on their function and how to organize them to interact with a code in terms of feedback control to fulfil the function of the PTS. The structure and function of the PTS then needs to be transferred into the context of the BBC Micro:bit material. At this step, the pupils need to have knowledge about how to program e.g., conditional statements that correspond to the intended feedback control of the assembled components with respect to their function, and how to combine this knowledge in terms of blocks in the editor. Hence, pupils need to know what the blocks represent in terms of real world conditions as well as in terms of programming concepts. They also need to know where to find these blocks in the editor, and to understand what the shapes of the blocks represent. As illustrated in Fig. 8, success in designing a PTS depends on understanding each of the two phenomena. Thus, pupils need to discern the critical aspects of both phenomena to transfer their idea of the PTS based on real world conditions into the BBC Micro:bit context.

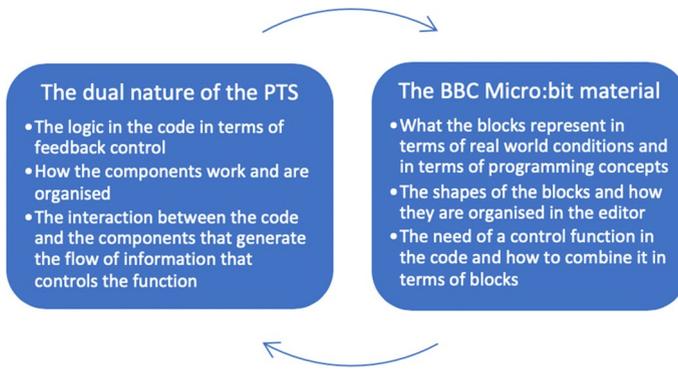


Fig. 8 The necessary knowledge in terms of critical aspects related to the two phenomena

Discussion

As a way to develop pupils' understanding of PTS and digital technology, activities such as designing PTS with different programming materials has become part of technology education. If the intention of using programming materials is to develop pupils' technological knowledge, it is necessary to reflect on what phenomena are involved in the process, what the critical aspects are, and what this means in terms technological knowledge. This study shows that the process of designing a PTS with the BBC Micro:bit material involves two interrelated phenomena: the dual nature of the PTS and the BBC Micro:bit material. Success in the process is related to what extent pupils understand these two phenomena, which encompass both conceptual and procedural knowledge related to the critical aspects they are able to discern. Thus, a thorough understanding of the two phenomena seems to be a prerequisite for being able to transfer the idea of a PTS based on real world conditions into a PTS in the BBC Micro:bit context.

The analysis of real world conditions in relation to the PTS

When taking on a task that requires designing a PTS, pupils need to analyse the real world conditions in relation to the problem to be solved. This involves procedural knowledge on how to conduct the analysis as well as conceptual knowledge related to the phenomena involved. This study shows that pupils need both conceptual and procedural knowledge with respect to the dual nature of a PTS (i.e., the structure and function of PTS). To achieve the desired outcome, pupils need to understand how to physically organise components and how to control these components with a logical code that realises a specific function. However, pupils approach the structure and function of a PTS in different ways, which could be related to different levels of systems thinking. The pupil pairs in this study were required to design a burglar alarm where the function was based on feedback control either using a change in light level or a change in movement. The pupils needed to organise the components and relate this organisation to the logic in the code they prepared to solve the given task, aspects that Cederqvist (2019) previously found critical. In the present study, several of the pupils were unable to transform their initial idea of using feedback control to their PTS via an appropriate code. These difficulties seem to be based on their limited

understanding of how components work (e.g., sensors) and how these components send feedback signals that are evaluated based on the conditionals written in the code. Thus, critical to understanding is the pupils' ability to determine whether a conditional is met and how information is sent to an output where the function is fulfilled. Similar results have been found in previous studies by Slangen et al. (2010) and Mioduser et al. (1996). That is, this study and previous studies have concluded that pupils designing a PTS have difficulties solving real world tasks because they do not understand how components work and how to use feedback control and the flow of information to control the components. These results indicate that pupils need to understand the structure and the function of a PTS using systems thinking to solve real world problems based on understanding the parts, how the parts interact, and the system as a whole (Booth Sweeney and Sterman 2007).

Assembling and coding of the PTS in the BBC Micro:bit context

In this study, BBC Micro:bit was used to transfer the pupils' ideas to their intended PTS. However, the pupils had diverse experiences using the BBC Micro:bit based on how they understood the different properties of the material, which may reflect the pupils' different abilities. The findings indicate that pupils need some basic understanding of what the blocks represent in terms of real world conditions in order to produce usable code. However, they also need to understand how the blocks can be combined to represent their intended control function in the PTS. Although the shapes of the blocks facilitate and guide pupils in how to combine blocks, we can see that this is not enough. That is, if the pupils do not understand what the blocks represent in terms of programming concepts, their production of code based on the shapes of the blocks is random, as seen in both category 1 and category 2. Even if the Micro:bit editor were structured in a way that made it easy for pupils to find the blocks they needed, the pupils would need to understand what the tabs in the editor represent as well as what the blocks represent in terms of programming concepts. The pupils in this study had difficulties understanding what the blocks represent and lacked a deeper understanding of programming concepts, results also found in previous studies (Grover and Basu 2017; Ivarsson 2003). These findings emphasise the importance of teaching conceptual knowledge when teaching programming: i.e., teaching how blocks represent conceptual knowledge and how conceptual knowledge is related to the procedural knowledge necessary for producing a code using blocks that control the PTS.

For pupils, the most difficult part using BBC Micro:bit to design a PTS is producing the code for the control function. All pairs of pupils were planning to design a burglar alarm using feedback control based on the analysis of real world conditions either by using a change in light level or using a change in movement. Hence, they were to combine blocks to produce a code that used a conditional statement to control how components interacted and therefore satisfying the function of the PTS. This difficulty indicates that teachers need to help their pupils understand the physical structure and function of the PTS and the properties of the BBC Micro:bit.

The ability to transfer the idea of a PTS into the BBC Micro:bit context

In the process of designing a PTS, the pupils' understanding of a PTS based on real world conditions requires the pupils to analyse the structure and function of the PTS. The structure and function of the PTS then needs to be transferred into the context of the BBC Micro:bit.

Hence, the process of designing a PTS implies that the two phenomena are interrelated. That is, pupils' ability to fulfil the PTS is based on the extent they are able to understand the phenomena involved and their ability to make a fit between these phenomena (de Vries 2005). Thus, it is necessary for pupils to discern the critical aspects regarding both phenomena if they are to transfer their PTS idea into the BBC Micro:bit context. Parallels may be drawn to previous findings by Cederqvist (2019) concerning pupils' ability to transfer their understanding of structure and function of PTS in the BBC Micro:bit context to the structure and function of PTS in an everyday context, which depends on the pupils being able to discern all critical aspects in the previous context.

The results in this study show that for pupils to fulfil the function of the intended solution they need to secure qualitative technological knowledge that refers to both the problem to be solved as well as the programming material used. This knowledge encompasses both conceptual and procedural knowledge related to the two phenomena (i.e., the dual nature of the PTS and the BBC Micro:bit material) defined as critical aspects. Figure 8 illustrates the necessary knowledge in terms of the identified critical aspects.

In the design process, there is a movement between the structural and functional nature (de Vries 2005). The results show that pupils adopt different levels of systems thinking to facilitate this movement when representing real world conditions in the PTS and further into the BBC Micro:bit context. However, pupils' ability to understand and use the BBC Micro:bit material is an important factor for the outcome in the process. The ability to understand and handle the programming material encompasses both procedural and conceptual knowledge that refers not only to the material itself but also to a general understanding of programming concepts that are necessary for fulfilling the PTS. In this study, feedback control was defined as a critical aspect. Although some pupils were able to use feedback control, they were unable to produce code for a conditional statement.

Implications for teaching

Pupils can design a PTS without discerning the critical aspects found in this study. That is, pupils are able to solve rather advanced technological problems including programming with the support of the visual and interactive programming material without fully grasping these critical aspects (see Ivarsson 2003). However, several studies (Cederqvist 2019; Ivarsson 2003; Kalelioglu and Gülbahar 2014) show that the use of different programming materials does not automatically develop pupils' understanding of concepts that can take them beyond the specific problem-solving activity. If the intention of using different programming material is to develop pupils' understanding of conceptual and procedural knowledge related to technology, programming, and the process of designing a PTS, it is relevant to reflect on what phenomena are involved in the process and how pupils understand and experience these phenomena. This study shows that there is a complexity of critical aspects that are necessary to discern during the process and these are related to both the structure and function of the PTS as well as to the BBC Micro:bit material. Teachers should not assume that their pupils will automatically discern these critical aspects. Teachers need to ensure that pupils develop knowledge beyond these activities by addressing the two interrelated phenomena in the process and helping pupils discern these critical aspects. That is, if the intention of using programming materials in the process of designing PTS is to develop pupils' understanding of PTS and digital technology, the activity should not be limited to 'making' a PTS as this approach will 'black box' the phenomena the pupils need to understand, and thus, the outcome in terms of technological knowledge will be poor. As Barak and Zadok (2009) suggest, such an approach will

result in pupils being blind to the relationship between designing a PTS and the subject matter of technology.

Conclusion

In the process of designing a PTS with the BBC Micro:bit, there are two interrelated phenomena that need to be understood and dealt with: the structure and function of the PTS and the BBC Micro:bit material. Pupils' ideas of a PTS based on real world conditions initially need to be analysed in relation to the structure and function of the PTS. The structure and function of the PTS then need to be transferred into the context of the BBC Micro:bit material. Pupils' ability to fulfil the PTS is then based on to what extent they are able to understand both phenomena involved and to accurately connect these phenomena (de Vries 2005). Moreover, pupils need to discern the critical aspects regarding both procedural and conceptual knowledge. Pupils need to know what components to use based on how the components work and how to organize the components to interact with a code in terms of feedback control. This understanding is closely intertwined with knowing how to program e.g., how to produce and use a conditional statement and how to combine the blocks in the editor. Hence, pupils need to know what the blocks represent both in terms of real world conditions and in terms of programming concepts. They also need to know where to find these blocks in the editor and how the shapes of the block should be interpreted. This knowledge is necessary to grasp for the pupils to design and program a PTS. If the intention of using programming materials such as the BBC Micro:bit in the process of designing PTS is to develop technological knowledge with respect to PTS and digital technology, then it is necessary for teaching to ensure that knowledge related to the phenomena involved is the outcome of the activity.

This study's results indicate that future research should investigate the dynamics and the sequential development of the process of designing a PTS with programming material such as the BBC Micro:bit. In addition, future studies should investigate what affordances and constraints are provided by the programming material concerning digital and technological knowledge.

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