Uncovering Procedural Knowledge in Craft, Design, and Technology Education: A Case of Hands-on Activities in Electronics

Matti Pirttimaa[1], Jukka Husu[1], Mika Metsärinne[1]
[1]Department of Teacher Education, University of Turku, P.O. Box 175, 26101 Rauma, Finland
matti.pirttimaa@utu.fi

Abstract Different knowledge types have their own specific features and tasks in the learning process. Procedural knowledge is used in craft and technology education when students solve problems individually and share their working knowledge with others. This study presents a detailed analysis of a one student's learning process in technology education and the procedural knowledge used during learning tasks. Thus, procedural knowledge is mainly produced when acting, and includes students' goal-directed actions related to the craft, design and technology processes and their learning content. These knowledge practices also include multiple interactions with teachers and other students. The findings show six different knowledge practices: observing, checking and asking, revising, guided representative action, self-directed representative action, and comprehended action. These knowledge practices actively relate to each other, and, in concert, they constitute chains of actions that constitute two different types of procedural knowledge: proactive knowledge and executive knowledge. We conclude by discussing how these knowledge practices can be used to develop our understanding of the teaching and learning of craft, design and technology.

Keywords Procedural knowledge · Learning · Comprehensive school · Craft, Design and Technology education · Pupil's practice

Introduction

Knowledge and knowing have a central role in learning and instruction within various individual or institutional contexts. Knowledge has been determined with a wide variety of properties and qualities in the research in learning and education (Alexander, Shallert & Hare 1991; de Jong & Ferguson-Hessler 1996). In the philosophy of technology, originally based on Mitcham's (1994) framework, four modes of the manifestations of technology have increasingly come to be applied to technology education: technology as object, technology as knowledge, technology as activity, and technology as volition (Ankiewicz, Swardt & de Vries 2006, 119). Two of these modes are closely related to the current study, namely technology as knowledge and technology as activity. Technological knowledge is used for imagining and modeling inside pupils' minds, as well as for speculating, exploring, clarifying, validating and critical appraisal. These mental processes, in turn, are realized in pupils' learning activities. Therefore, technology is characterized as comprising both minds-on processes (complex thinking and problem solving) and as hands-on practical activities. (McCormick & Davidson 1996, 232; Ankiewicz, Swardt & de Vries 2006, 133.)

Although prior research has detailed many theoretical considerations, there is a need for empirical research on differentiating the aspects and qualities of young pupils' technological knowledge use in craft, design, and technology (CDT) education. Procedural knowledge refers to knowledge about action, or knowledge transmitted through processes of making things (Shraw 2006; Anttila 2009.)

Learning and teaching technology practice has recently attracted more scholarly attention. For example, Dagan (2015) has studied the views on technology of student teachers working in kindergartens and also their opinions about integrating technology into their work with children. The results of the study indicate that participating in a technology course significantly increased the student teachers' technical vocabulary. Student teachers also became more aware of the nature of technology as an activity (or process). Gumaelius and Skogh (2015, 188–194) studied the lesson plans of technology teachers' at lower secondary school during a Boost of Technology development project. Their results showed technical activities were present in all of the lesson plans examined; however, there was a lack of the required progression in the presented themes and learning activities. Furthermore, the quality of the outcomes expected of pupils was rarely outlined. Schooner, Klasander and Hallström (2015, 361) have studied teachers' views of knowledge assessment in technology education in Sweden. The participating teachers focused on several areas in their assessment of students' skills and knowledge of technological systems. However, all of the teachers had difficulties in grading their student's intermediate and advanced levels of understanding of technological systems.

The review above confirms research has covered technological knowledge in different settings. Nevertheless, there is a need for more nuanced analysis of the pedagogical practices through which the structures and modes of procedural knowledge are constructed among students. Such information would help identify the gaps between expected outcomes and actual results in pupils' learning. It also helps to better determine the possible learning aims and outlines for students' accessible progression. Furthermore, the information can help teachers to develop more powerful ways to motivate students to participate in technology education practice (see below). As a response to the need, this article scrutinizes one pupil's learning within practical doing and working processes in CDT education.

According to Parkinson and Hope (2009), the sensory informed perceptual side of experience, practical doing experiences and the conceptual dimension of experiences jointly contribute to the special qualities of technology education (Parkinson & Hope 2009, 255). Hill (1998) emphasizes the opportunities for the student's own creative processes and real life technological problem solving. We suggest technology education provides a natural learning environment for learning among young children and offers fertile ground for a variety of types of intelligence and learning styles (Hill 1998, 211). Technology serves for the students as an activity that involves the social and physical context as well as intellectual space for learning, structured by the objects and tools of action. Research on student learning in the technology context has to take into account the conceptual and procedural or practice related understanding, but also the manner in which technological tools and objects effect and interact with student thinking and doing (Jones 2009, 407).

Crafts is a very practical subject affording opportunities for students to learn by doing (Finnish National Board of Education 2004; 2014). Nevertheless, the subject has many interfaces with science, technology, engineering, and mathematics. For that reason we use the term CDT education in this paper (see Metsärinne & Kallio 2014). Many students find it easier to grasp the challenging and abstract contents of science and technology when they are presented through practical work. The topic of crafts as a subject in Finland and other countries is described in more detail in the articles of Metsärinne and Kallio (2014) and Metsärinne, Kallio and Virta (2015).

The current research examines one pupil's actions and practice in an authentic Finnish comprehensive school CDT education context—specifically related to electronics and technology.

We use the term “practice” in the sense of goal-directed physical, psycho motor, social, and mental actions related to the CDT processes and learning contents.

The following research questions were set to guide the research:

> What qualities of procedural knowledge does a pupil employ in her practices in CDT education?
> How does procedural knowledge appear in the pupil’s learning in CDT education?

Theoretical background

Ryle (1949) makes a distinction between “knowing how” and “knowing that”, that is, between the human capacity to find out truths or organize and exploit them and that of knowing certain truths or facts per se (Ryle 1949, 28). The same distinction is often expressed as that between procedural knowledge (i.e., the knowing how) and declarative knowledge (i.e., the knowing that form). The latter form has also been described as conceptual or propositional knowledge in the scientific literature across disciplines (de Jong & Ferguson-Hessler 1996; Jones 2009; McGormick 1997; Parkinson & Hope 2009; Sahdra & Thagard 2003; Shraw 2006). In CDT education, students explore and try to resolve complex and interrelated technological problems that involve conceptual, procedural, societal, and technical variables (Jones 2009, 407).

Procedural knowledge is a research topic in various disciplines and subject areas. There is a large volume of research related to acquiring procedural knowledge in mathematics (e.g., Schneider, Star & Rittle-Johnson 2011; Star 2005), CDT education (Hope 2009; Jones 2009; McCormick 1997; Parkinson & Hope 2009, Metsärinne, Kallio & Virta 2014) and engineering education (Leppävirta, Kettunen & Sihvola 2011). Research interest largely focuses on STEM education, (Lin, Hou, Wu, & Chang 2014). There has also been interest in the topic in educational psychology (Shraw 2009), cognitive psychology and neuroscience (Pezzulo 2011), molecular biology (Sahdra & Thagard 2003) and craft education (Anttila 2009; Risatti 2007).

Procedural knowledge refers to how we do or make something (Schraw 2006, 249) and declarative knowledge refers to facts, concepts and the relationships among concepts or to an integrated conceptual understanding. This kind of integrated conceptual map might be designated as structural knowledge, mental models, or schemata. A schema provides a mental framework that guides perception and understanding about some distinct domain of knowledge. (Schraw 2006, 247–248.) Higgs (2012) uses the term practice knowledge, referring to the combination of propositional and experiential knowledge. According to Higgs, propositional knowledge is based on science and theorization and experiential knowledge is derived from personal and professional practice experience. Practice knowledge requires empirical, critical, practical, and aesthetic ways of knowing (Higgs 2012, 77–78). Procedural knowledge is knowledge about action, or knowledge transmitted through the process of making things (Shraw 2006; Anttila 2009).

> Procedural knowledge – or rather, understanding – includes the execution of single actions and entire chains of actions, or processes. The concept ‘procedural’ emphasises the gradual unfolding of ongoing processes. One advantage of using this concept is that it can involve all senses, hands-on experience and practise at solving problems or the understanding of the limitations of some specific solutions.
>
> (Anttila 2009, 15)

The qualities of procedural knowledge are differentiated in the literature; so for example, knowledge about execution held by someone following another person who has done something would not be the same as that held by a pioneer of an action. Hence, execution and understanding are different exercises of knowledge, or different aspects of *knowing how* (Ryle 1949, 54–55). Furthermore, Sahdra and Thagard (2003) differentiate between a plan with specific instructions and steps to be followed and conducting an actual experiment. Procedural knowledge does not merely involve memorizing the steps of the relevant protocol, but is the knowledge of the forms of action and real experience gained for example in the laboratory or technology workshop (Sahdra & Thagard 2003, 482).

According to Parkinson and Hope (2009), procedural knowledge is intimately linked with conceptual knowledge as a consequence of cognitive capacities such as extrapolation, insight and analogies. This kind of cognitive–procedural intertwining arises through the interrelationship of thinking and making, artefact creation, materials handling, and acts of reflection that occur within any design, construction, and evaluative cycle (Parkinson & Hope 2009, 256). It is impossible to precisely distinguish procedural and declarative knowledge from each other, because there is always a need to use some terms and concepts to represent and describe the things being dealt with or worked out. According to Smith (1994), the distinction between procedural and declarative knowledge has meaning only in the context of an overall theory (Smith 1994, 101).

The term procedure is one of the main concepts related to procedural knowledge. McCormick (1997) references Stevenson (1994) in proposing the idea of different levels of procedures. On the very basic level the procedures are a simple, algorithmic series of acts directed toward known goals. On the second level the procedures are related to achieving unfamiliar goals, including strategic skills and problem solving. On the third-order level is a control function between the last two levels (McCormick 1997, 145).

Marzano (2010) proposes a hierarchy of procedural knowledge and distinguishes three stages of procedural knowledge: skills, strategies, and processes. From our point of view, the procedures could form the first stage of procedural knowledge alongside skills. Mastering procedures leads to the acquisition of skills, which are specific ways of mastering and performing various physical-manual or intellectual activities. The strategy is a way to choose the series of trials required to solve the problem in the relevant case. The process is a wide category comprising the execution of the series of skills and strategies to resolve a problem or reach a goal. Furthermore, within this hierarchy exists another: the stage of awareness, the stage of execution, and the stage of mastering, or the autonomous stage. During the first stage, the learner is aware of how the procedure, skill, strategy or process works but is not able to action it. During the next stage, the learner begins to execute the procedure but must think about it consciously while doing so, perhaps making errors. During the final autonomous stage the learner masters the procedure to the extent that he or she can execute it with little or no conscious thought (Marzano 2010, 81). Marzano's stage of mastering has similarities with the concept of tacit knowledge (Polanyi 1958; 1966) and is characterized by personal knowledge, involving the active comprehension of things known and actions that require skill (Gascoigne & Thornton 2013, 5). This tacit dimension can be found *in both individual and collective practices in versatile, implicit, informal, and unintentional ways… [and] its complexity and ambiguity are generally acknowledged* (Toom, 2012, 621).

Procedural knowledge in CDT education can be built up only by taking part in actions and practice-oriented processes, solving problems, or sharing activities inside the community of learning. Risatti (2007) states that in the context of crafts this type of knowledge concerns the ability to actually do or construct something and involves manual skill. *It is defined as skill acquired through practice or action, rather than [through] theory or speculation.* Risatti (2007, 99–100) refers here to Wilson's work (1998). The complexity of human cognition, compounded with the social factors and interactions with the material world, cannot be reduced to absolute facts, techniques, or routine strategies. In crafts, imagining and making something connect mind and body so that the mind extends through the body into the hands and tools (Risatti 2007, 170). From our point of view, the concept of students' practice is linked with the engagement in the CDT classroom practice with its multidimensional complexity, including the social context and interaction between the participants (cf. Jones & Moreland 2003, 53–54; Wenger 1998, 95). In classroom situations, the progression in students' learning appears for the teacher and for the student in the form of a gradual improvement in cognitive capabilities or conceptual understandings, as well as in procedural aspects in students' practice. It is not an issue of knowing / not knowing or can / cannot; instead, qualitative judgments are required (Jones & Moreland 2003, 59; Jones 2009, 410).

It seems that any aspects of knowledge are fluid, dynamic, and interactive. Any particular form of knowledge does not exist exclusively in one or another state (Alexander, Shallert & Hare 1991, 324.). Part of the complexity of the situation is due to different levels of procedural knowledge and the need to consider the *strategic thinking* required in learning and problem solving (McCormick 1997, 143). Hope (2000, 4; 2009, 49–50) suggests a third category of knowledge, strategic knowledge, which is connected with choosing the strategy to move the design forward through planning and practice activities toward the final product. In the current study, *procedure* is defined as a series of acts to perform some real, practical, or intellectual task.

Methodology

T*he case study method in researching CDT learning*

The case study method is a form of empirical inquiry that can be used to investigate a contemporary phenomenon in depth and within its real life context. The case study method is especially useful when the boundaries between the phenomenon and its context are not clear (Yin 2009, 18.). The current research scrutinizes the appearance of procedural knowledge for one female pupil in the sixth grade in primary school during hands-on activities in the context of CDT education. The phenomenon is considered through the pupil's practice and her interaction with the teacher and other pupils. The case is not restricted to the events surrounding the pupil but instead encompasses the whole social and operational context of the learning processes. During the CDT activities, the observed pupil constructed a microcontroller application, which reacted to darkness by illuminating a light emitting diode (led) in clothing to make people more visible in traffic at night. Each of the two lessons observed was 90 minutes long with a break of 15 minutes in the middle of the lesson. The lessons (total observation 180 minutes) took place in consecutive weeks.

The "intelligent clothing" project was carried out in southern Finnish urban teacher training school and implemented mainly during January–March of 2011. The aim of the project was to familiarize the pupils with the diverse content, materials, and technologies used in CDT education. The pupils were told before the start of the project that electronics, programming, and textile materials and techniques would be involved. During the ideation and introduction lesson the pupils formulated their own ideas for the intelligent clothing. At the end of the lesson, the pupils and teachers agreed an intelligent, environmentally reactive cap would be a common theme for the project. The pupils were able to use the virtual learning environment (called Opit, currently Sanoma Pro) during the project. Opit was a Finnish, commercial digital learning solution for educational purposes. It provided options for teachers and the students to create user accounts to access the email system and learning materials of the publisher, or for the users to design their own customized materials, learning tasks, and wiki platforms. Knowledge and examples—especially concerning electronics and microcontrollers—were presented in the virtual Opit environment. The main phases of the whole project were 1) the design and ideation phase, 2) the technology and electronics construction phase, 3) the textile crafts phase and 4) the combination and finishing phase of the project. In this article our focus is on the technology and electronics phase.

The first of the three technology lessons was an introduction to the basics of electronics and construction of the main prototype circuit board. The students also received an introduction to learning materials in the Opit virtual learning environment. One of the teachers demonstrated the installation of the components on the circuit board with the document camera and the principle of soldering and use of the soldering equipment.

The other teacher demonstrated the operation principle of the circuit and the layout of the components, presenting the Opit environment materials with a data projector and screen. This teacher also participated in the study as a researcher. The pupils then started to construct their circuits. This first lesson was excluded from the analysis because it was after this lesson that the participant pupil was selected. Only during the second and third lessons of the technology task was the participant observed for data collection purposes. Consequently, what was in fact the second lesson of the technology task is referred to in this article as the first lesson within the research project. In terms of selection of the participant the likely richness of the available data is one useful and important criterion in the case selection procedure (Yin 2006, 115). The stimulated recall interview (Lyle 2002) subsequently revealed that the pupil had little formal learning experience of the content relating to electricity and electronics. The pupil was a high-achiever and at the time was registering grades of eight out of ten in mathematics, and physics and chemistry, and grades of nine out of ten in textile craft, arts, and the Finnish language.

Data collection methods and instruments used

The observed pupil’s actions and social interactions were videotaped by a research assistant. Those recordings of the two lessons were used to analyze the pupil’s knowledge construction processes. Elan 4.40 video annotation software was used to mark significant episodes and to add annotations. The incidents and discourses between the participant pupil and the teacher or peers were transcribed within the Elan software interface. A deductive approach as analysis (Derry, Pea, Barron, Engle, Erickson, Goldman, Hall, Koschmann, Lemke & Sherin 2010, 10) was selected after the qualification of the research focus. This focus was constructed with the theory of declarative and procedural knowledge. Later, inductive processing of the data was conducted. The annotations were transferred from the Elan interface to Microsoft Excel for analysis and coding. The process was repeated several times with Elan and as an Excel matrix. The search categories were rearranged during the process, and rectifications, decoding and refinements made (See Saldana, 2009, 10).

> …when the major categories are compared with each other and consolidated in various ways, you begin to transcend the “reality” of your data and progress toward the thematic, conceptual and theoretical. … the actual act of reaching theory is much more complex and messy than illustrated.
>
> (Saldana, 2009, 11)

Saldana (2009) states that in any qualitative research, the coding consists of several coding cycles. Qualitative research demands thorough attention and deep reflection on the emergent patterns and meanings of human experience or phenomena being studied. Recoding can occur with a more adaptive and attuned perspective using the first cycle methods again, or using more sophisticated processes that might be employed during the second, third or whatever review of data (Saldana 2009, 10).

The episodes of the participant pupil's practice were sufficiently rich in data to permit further refinement into subcategories. Those subcategories in turn provided a database from which to draw conclusions on more general categories of procedural knowledge. The coding process also included the goal and content directed interaction with the teacher and the other pupils during the pupil's practice sessions. This resolution is supported by theoretical considerations, leaning on the view of Jones and Moreland (2003), Risatti (2007), and Wenger (1998) and their attention to social factors in learning.

All the participating pupil's acts and interaction situations were marked, annotated, and linked visually to the video data in the Elan interface. After various cycles and refinements the contents and transcriptions were considered as tabulated transcriptions, depicted in a detailed manner. The search for similarities and common themes throughout the data produced the first preliminary terms for the classifications: observing, asking and ensuring, acting, and comprehending. Those were further refined to a classification of observing, checking and asking, checking and action, representative action and comprehended action. Later the concept of representative action was divided into guided representative action and self-directed representative action. Finally, the term *checking and action* was replaced with the term *revising*. For example, an episode where the participant pupil was observing another student cutting wires for the led was classified as observing. The episode and the question… "Raimo (the teacher), what should I do now when I have this?" was classified as *checking and asking*. The results of the searching and research process are explained in more detail in the results section of the article.

Trustworthiness

We have taken various steps during our research and coding process to ensure the trustworthiness of the classification of the annotations. The stimulated recall method was used in the early phase of the research to ensure the reliability of video data and interpretation. The stimulated recall method is a research procedure in which videotaped episodes are replayed to individuals to stimulate and facilitate recall of their thinking or cognitive activity during the episode in question (Lyle 2002, 861–863). Two stimulated recall interviews were conducted to extract more information from the original video data on the pupil's learning and working process during the technology and electronics construction phase of the project. Those interviews were also videotaped.

At a certain stage, the analyzing process produced single annotations that essentially included several classification types of knowledge. To address that issue, the video material was reviewed several times, and the annotation in question was divided into different components that better accorded with the separate knowledge types. In some cases researchers selected the most descriptive class for the annotation. The inter-rater reliability (Cohen, Manion & Morrison 2011, 210) of the classification of the knowledge types was determined. Around 15 % of all practice annotations were chosen at random and checked by an external informed expert. For the inter-rater checking, the expert was informed about the theory and classification used in the research and watched the video clips about annotations before recording a personal interpretation of the knowledge type. The expert review led to 77 % of the checked annotations according with the original classification. After rechecking, watching the video episodes together and discussions, there was consensus between the research team and external expert on 96 % of the checked annotations. The remaining 4 % were interpreted as being of the either or not type, that is, either of the interpretations were feasible. The process suggests a high level of reliability and trustworthiness.

Results

The qualities of procedural knowledge as part of the pupil's practice

The analysis conducted in the current research revealed six different practice activity types or phases in the pupil's technological inquiry. We label them *observing, checking and asking, revising, guided representative action, self-directed representative action and comprehended action.* These terms were selected after consideration of the differences and equalities between the annotations. With these identified types we express the plurality of pupil's activities. Even though only the practical and appreciable activities are reported, we would stress that practical skills and thinking skills are inextricably linked. Pupils could be carrying out high-order thinking in terms of critical or reflective thinking and decision making about their diverse practical activities without it being obvious to the researcher.

Observing represents the participant pupil monitoring the teachers' supervision activity or that of classmates. This type of activity does not include any appreciable practical actions or involvement on the part of the participating pupil. Instead the student is orienting him- or herself toward conducting a trial or anticipating a solution to the problem or advancing his or her working process. An example of this kind of monitoring is illustrated in the transcriptions related to the situation.

> ***The teacher M:*** *It is connected from here… (the teacher is checking Anna's design plan) So, this is connected to there…*
> Anna is listening to and watching the teacher's explanations [observing]…
> ***Anna:*** *"Yes, here..." Anna says, and marks something on the design plan …*
> ***The teacher M:*** *…and another becomes here… from here you lead this to there like that, okay (the teacher says unclearly) and then… between this there is a cap like that… this cap to there like that…*
> Anna is listening to and watching when the teacher M explains Anna's design plan. Anna is making some brief affirmation comments. [observing]

Checking and asking was exemplified by the pupil actively addressing the teacher or her classmates in order to resolve a problem and getting more information in a particular situation. She attempts to progress a problematic situation, or avoid the uncertainty related to her attempts to manage. The observations of the pupil showed she had a tendency to ensure she was doing things the right way by checking even basic tasks with the teacher. It is important for the teacher to recognize the student's strategy and the way she behaves in problem solving situations. The teacher should encourage the pupil's rational cognition, individual endeavor, and independent problem solving. The following excerpts illustrate the student's *checking and asking* activity:

> ***Anna:*** *Johanna, do you have it like that?* Anna is asking and raising the board so that Johanna can see it... [checking and asking]
> ***Johanna:*** *Yes, push it down so…*

Revising concerns the pupil's own attempt to consider a particular detail or problem. The action of considering comprises an evaluative aspect. In most cases, the pupil does not have a particularly deep insight into the problem or situation, and consequently, the pupil makes a rough attempt to check some detail related to the situation. The following is an example of the revising activity:

> Anna is sitting down on the stool beside the work bench and bench vise.
> **Anna:** *Are these allowed to be touching each other?* Anna is asking about the positioning of the joints on the surface of the circuit board.

The teacher doesn't reply. Anna is viewing the bottom of the circuit board and she alters the position of the pins of the LDR resistor which are protruding from the board. [revising]
After that she starts to clamp the circuit board between the jaws of the bench vise, but then reexamines the board, and fixes the component installment. [revising]

Guided representative action is characterized by the pupil's active participation directed to resolving a particular problem or striving to move forward under the guidance of the teacher or some other pupil. It is a justifiable habit of working in a situation involving learning new procedures, ways of action and operating, or learning new skills. An example of that kind of activity is offered below:

The teacher M: *… Isn't it the case that you can also put the resistor horizontally? Like direct onto the board…*The teacher points to the resistor illustrated in the design plan.
Anna is testing to set the resistor on the board, and on the same time she follows the teacher's guidance. [guided representative action]
The teacher M: *Another one is placed for example here* (the teacher M points with the tip of the wire the place for Anna).

Self-directed representative action is characterized by the pupil's active, independent efforts committed to the task. These activities are often quite simple routine activities related for example to soldering the components or finishing the soldered joints:

Anna has performed the stages of soldering a resistor on to the circuit board. After that she cleans the tip of the soldering iron. [self-directed representative action]
Anna opens the jaws of the vise and releases the circuit board. [self-directed representative action]
She walks toward another work bench, takes the pliers, and after a while goes to the garbage can and cuts off the remainder of the resistor legs. [self-directed representative action]

Comprehended action relates the pupil's performance and gaining new insight into a particular situation concerning the task in hand. An example of this kind of personal endeavor is illustrated in the next excerpt:

The Teacher M: *Now you have to look at the paper to see where the resistor has to be assembled.*
Anna: *So, which one of the two resistors is that? … This one?* Anna takes a look at her design plan and points to the resistor on the paper.
Anna: *So it goes…here* (Anna recognizes the place for the resistor on the real circuit board).
Anna is bending the legs of the resistor a little and starts to adjust it on the board. [comprehended action]
The resistor does not fit on the board, and she bends the legs a little more [comprehended action]

The video data recorded 697 pupil's practice annotations. Self-directed action is the most common practice activity type (about 35 %, see Table 1). Checking and asking seems also to appear often in the pupil's practice (about 26 %). This can be seen as a consequence of the new and challenging subject area related to electronics and programming and the task to construct a programmable microcontroller device. The division of the phases of the pupil's activity types or technological inquiry in our video data is recorded in Table 1.

Procedural knowledge in the pupil's learning

The practice activity types are intertwined with each other. Further, they constitute a series of acts building up two different types of procedural knowledge, here called *proactive knowledge* and *executive knowledge. Proactive knowledge* is knowledge that prepares the pupil with sufficient preliminary knowledge to begin acting, working, and solving practical problems. This kind of knowledge is illustrated in the next quotation related to it:

> Anna reviews her design plan. [revising]
> ***Teacher M:*** *"What did you have to do?"*
> Anna is looking at the bit of the Strip-board where the LED is jointed on, simultaneously turning around the bit of the board. [revising]
> ***Teacher M:*** *You can go and solder it. Then you can tighten it (the wire)…*
> ***Anna:*** *That one?* [checking and asking]
> ***Teacher M:*** *Yes, solder it there.*
> ***Anna:*** *You mean completely?* [checking and asking]
> ***Teacher M:*** *Yes, thus… you see you have here that… ee… that you see this… this … comes through here… eh? You can solder it there…*
> Anna is observing carefully the teacher's M. explains. [observing]

Table 1 Phases of a pupil's practice activity types and technological inquiry

Observing	Checking and asking	Revising	Guided representative action	Self-directed representative action	Comprehended action
9,9 %	25,7 %	14,1 %	11,0 %	34,8 %	4,6 %
(**N** 69)	(N 179)	(N 98)	(N 77)	(N 242)	(N 32)
The pupil is monitoring the teacher's / other pupil's activities or explanations	The pupil is actively making contact with the teacher or classmates in order to resolve a problem	The pupil is considering a particular detail or problem	The pupil is actively participating to resolve a problem or striving to take it forward under the guidance of the teacher or other pupils	The pupil is actively and independently putting routine type effort into completing the task	The pupil is performing and gaining insight into a particular situation concerning the task in hand

Proactive or orienting knowledge is developing in the situations where the pupil can observe, ask for support, or do preliminary testing and analysis on the problematic situation.

Executive knowledge in turn concerns performing and actively resolving specific technology problems. This kind of knowledge is illustrated in the next example and in Figure 1:

> ***The teacher M:*** *In fact, drag them from here on the top, take them off.* (The teacher M. says, pointing to the top of the board for Anna.)

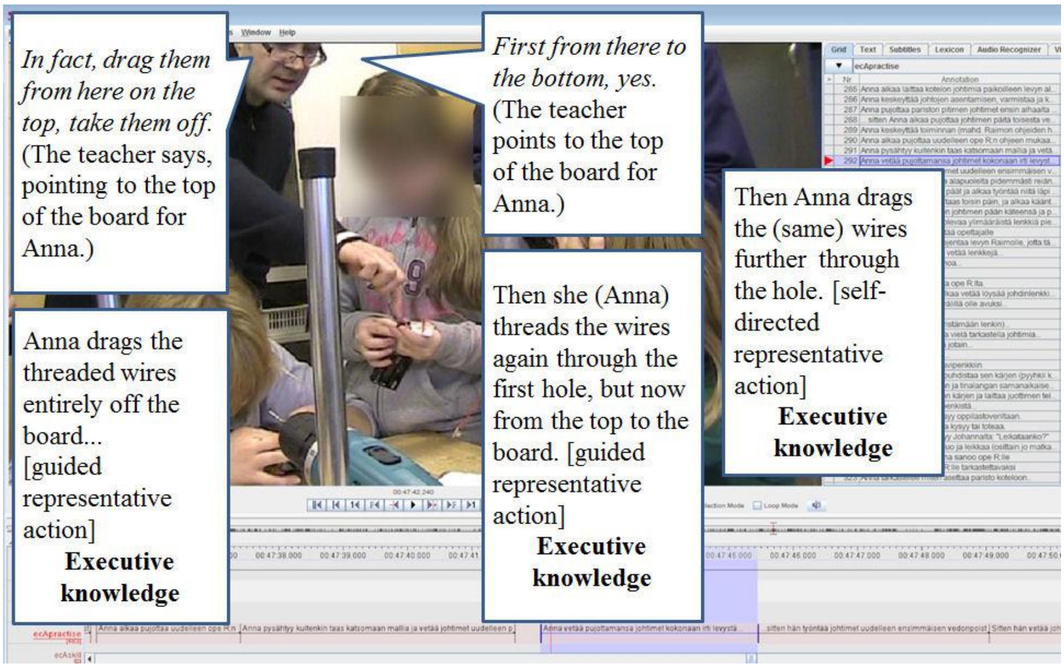

Fig. 1 Anna is setting the LDR resistor on her board under the guidance of the teacher, continuing the activity by herself

> Anna drags the threaded wires entirely off the board... [guided representative action]
> ***The teacher M:*** *First from there to the bottom, yes.* (The teacher M. points to the top of the board for Anna.)
> Then she (Anna) threads the wires again through the first hole, but now from the top to the board. [guided representative action]
> Then Anna drags the (same) wires further through the hole. [self-directed representative action]

The current research analysis established two main different types of a pupil's procedural knowledge. Proactive knowledge and executive knowledge are very balanced and ranked close to each other in the case of the participant in this research (Table 2):

Table 2 Types of procedural knowledge in technological inquiry for the pupil in this study

Observing	Checking & asking	Revising	Guided representative action	Self-directed representative action	Comprehended action
Proactive knowledge inquiry 49.6 % (346)			Executive knowledge inquiry 50.4 % (351)		
A pupil's procedural knowledge continuum ◄──►					
Example of proactive knowledge core practice: The pupil is orienting herself toward or anticipating a trial or solution to the problem or progressing her working process. She may be monitoring, making contact with the teacher or other pupils, or roughly attempting to control / consider a particular problem.			Example of executive knowledge core practice: The pupil is actively working to resolve a particular problem or striving to progress independently or under the guidance of the teacher or the other pupils. She may have comprehended performance and be gaining insight into a specific situation concerning the task in hand.		

The pupil's practical work and forms of procedural knowledge can be seen to constitute different combinations, which in turn can be seen as different procedures. For example, the series of the pupil's acts related to designing the connections for the components on paper was: first, the participant pupil (Anna) is observing the teacher explaining something to another pupil *(observing).* After that Anna asks the teacher something, at the same time looking at her design *(checking and asking).* Then, she looks at her design to try to find the place for a leg of a component on the basis of the teacher's request *(guided representative action)*. She is looking at the screen where the teacher is pointing *(guided representative action)*. "Here", she recognizes the best place for the leg, turning to point out the place of the leg on the design plan *(comprehended action). This episode is illustrated in Table 3 below:*

Table 3: An example of the combination of the pupil's activity and procedural knowledge

Types of practical activities/phases of the pupil's inquiry		Types of procedural knowledge
Observing	Student's activity continuum	Proactive knowledge
Checking and asking		Proactive knowledge
Guided representative action		Executive knowledge
Guided representative action		Executive knowledge
Comprehended action		Executive knowledge

Observing and after that the act of *checking and asking,* comprise the proactive or anticipatory phase of the procedure in Table 3. Subsequently the procedure moves toward its executive phase, which in turn consists of the pupil's representative actions under the teacher's guidance, continuing to comprehend the placement of the leg of the component.

Many different procedures can be seen in our experiment. Some are executed more independently by the participant pupil, and they sometimes contain quite simple action sequences related for example to soldering a component onto the circuit board. Before embarking on the soldering procedure, the student might prepare herself by asking questions of the teacher and observing the teacher's actions, before moving on to do the soldering. Finally, the pupil might check her results and ask the teacher about a particular detail on their soldered joint. In summary, the participant showed how a student could start the procedure by *observing* and *checking and asking*, which can be seen as proactive knowledge. After that, the representative guided actions or self-directed actions related to the procedure are executed. The end of the procedure may be marked by a repeated checking of the actions completed.

During the analyzed lessons many variations between the procedures were observed. There are challenging situations in the pupil's practice related to the placement and connections of the components on the board. Hence, there were episodes when proactive knowledge and executive knowledge existed alternately and consecutively many times over. On the other hand, some episodes consisted entirely of purely proactive knowledge usage or purely executive knowledge actions.

Discussion

This paper offers evidence that it is possible to describe and classify the pupils' technological practice in a systematic manner, and to isolate interpretative, but systematic types of procedural knowledge from video data. Six different practice activity types or phases of pupil's technological inquiry were found in our research analysis concerning the participant pupil's CDT practice. The exploration of authentic practice and learning from the perspective of pupils' use of knowledge is important for developing CDT teaching and learning. This kind of knowledge is necessary to establish strategies for teachers to advance the students' learning process of understanding the ill-structured phenomena and contents of technology.

The participant pupil had no previous experience of the content of electronics before the "intelligent clothing" project. Everything was new for her. In the first stimulated recall interview, the pupil reported how at first she thought she would never succeed with the project. Step by step she learned more, and eventually she came to enjoy working with electronics. At first she needed support as she became familiar with the concepts of and practices used in technology, but gradually she began to manage more independently in different situations. The pupil's basic knowledge and practice management, including simple technology working procedures developed. According to the results, self-directed representative action is the most common practice activity type (35 %). This finding can be seen as an indicator of the pupil's progress in learning technology in practice. This also supports the view that Finnish CDT education is a very practical subject that affords genuine opportunities for a pupil to learn by doing.

The current research illustrates the case of a pupil's gradual improvement in the procedural aspects of learning and in cognitive capability or conceptual understanding (cf. Jones & Moreland 2003, 59; Jones 2009, 410.) These areas support each other, and it appears that executing the same procedures independently (via self-directed representative actions) and repeatedly is an expression of the progress of execution or management of a procedure or a skill. Sometimes the data threw up specific evidence of the variance between the performance of activities, such as soldering tasks. Even if the participant pupil managed well in the performance of the task, the next time she attempts it she may not perform the soldering so competently, because the skills or procedures have not yet become automatic for her. The circumstances may vary slightly, or the tools not be in the same condition every time. If pupils encounter a similar variance between situations, there is always a possibility that they will not manage the execution of the task competently again.

The single pupil case informing the current research does not permit generalizations about the findings. Those findings can however be used as research tools for the classification of pupils' practice and as common signposts for future research. It is also clear that in this kind of short learning period, knowledge structures and management of procedures do not become deeply embedded and automated. More practice of learning is needed for deeper knowledge and automated skills to develop. If the observation period had been longer, it would have been possible to draw more precise conclusions on the progression of the pupil's knowledge and skills related to the execution of practical tasks and problem solving situations. However, the analysis does reveal single comprehended acts and solutions arising from the pupil's efforts at cognitive and functional practice.

Making unambiguous interpretations about the structures of procedures or skills is difficult. Even if the practice episodes are unambiguously identifiable, in many cases in the analysis the starting points and the ends of the possible procedures are interpretative. When a procedure starts and ends is certainly a matter of interpretation, as is when one procedure changes to another. For that reason we have not logged the numbers or percentages of the various and different procedures in our experiment.

Implications

The implications for future instruction and organizing pupils' learning can be implied from the results of the systematic analysis of real life learning situations. The lack of pedagogic strategies to support students in developing procedural knowledge in the process of solving technological problems constitutes a challenge for teachers (McCormick 1997, 152). That lack is linked to the teacher's technological pedagogical content knowledge TPACK: the highly applied knowledge that supports content-based technology integration in teaching and learning (Harris & Hofer 2011, 212). This kind of knowledge is characterized by connections, interactions, affordances, and constraints between and among content (electronics and microcontroller project in this research), pedagogy, and technology (Mishra & Koehler 2006, 1025).

When planning technology projects in the future, more attention should be directed to the ways a teacher might offer the pupil support in resolving problems. In the current project, the learning material was presented in the Opit internet environment. The user interface of the Opit environment was not the best possible, and the participant pupil was not sufficiently familiar with the tool. Perhaps some of the supporting material should also be made available on paper, which could be more available during working activities. This area of research would also benefit from access to easy-to-use mobile compatible internet materials.

The pupils used a blueprint or the design plan of the layout of component connections on which the teacher had provided the basic structure, and which had to be completed by the pupils. Originally this complementary task was homework for all pupils, but they could not manage the task. Eventually the task was conducted during the first analyzed lesson under the teachers' guidance. Pupils inserted the extra components and connections on to the paper by following a layout model presented on the data projector screen. This episode was an example of the need to recognize the gaps between the teacher's expectations and the pupils' actual skills in the practice of learning.

Children need conceptual knowledge to understand the concepts and phenomena around subject matter. That knowledge both helps them to communicate and construct their conceptual understanding, and also to exploit such knowledge in the design, problem solving, and manufacturing processes (Hope 2000). Furthermore, being involved in practical work helps students better understand abstract and complex concepts and phenomena. By using her design plan as a source of information and by getting support from the teacher in critical situations, our participant pupil could assemble the components in the right place on her board. These kinds of single connections are prerequisites for the operation of the final device. Using particular commands in the final programming, making the whole script, and running it from a personal computer through the programming cable to her device meant she was able to make her final device function. This whole process may help her to understand the movements from single acts to procedures and on to the process of getting a device to function in the desired manner.

In the future, we intend to scrutinize the conceptual knowledge related to technology education, and to examine the complex interplay between the declarative and procedural forms of knowledge. CDT education in Finland includes a range of content directly connected with usage and the understanding of everyday uses of technology. It is important to identify appropriate projects that could help students combine learning practice and the everyday challenges encountered through technology. The intelligent clothing project and the current research can help illuminate the practice of learning CDT.

Acknowledgements

We are grateful to Anna for her collaboration and willingness to take part to our research project. We also appreciate Miikka Wikholm helping with the inter-rater checking process of the data analysis, and the other colleagues sharing our endeavor to complete our research work. We are also very grateful to Professor Douwe Beijaard (University of Eindhoven) for his critical and constructive comments for the manuscript. We also thank the Finnish Cultural Foundation, Satakunnan Rahasto this project, thereby enabling the planning and execution of the intelligent clothing project, the data collection, and the first steps of the research.

References

Alexander, P., Schallert, D. & Hare, V. (1991). Coming to terms: How Researchers in Learning and Literacy Talk About Knowledge. *Review of Educational Research 61* (3), 315–343.

Ankiewicz, P., De Swardt, E. & de Vries, M. (2006) Some Implications of the Philosophy of Technology for Science, Technology and Society (STS) Studies. *International Journal of Technology and Design Education 16* (2), 117-141.

Anttila, P. (2009). An expanded concept of knowledge in research on art and craft works. In Kaukinen, L. (Ed.*) Proceedings of the Crafticulation & Education Conference. Techne Series. Research in Sloyd Education and Crafts science A: 14. Helsinki: Helsinki University Press.* Available from URL: https://helda.helsinki.fi/bitstream/handle/10224/4810/Kaukinen_verkko.pdf?sequence=2 (accessed March, 2013)

Cohen, L., Manion, L. & Morrison, K. (2011). *Research Methods in Education.* New York: Routledge.

Dagan, O. (2015) Kindergarten student teachers' attitudes towards and perceptions of technology: the impact of a one year pre-service course. In Chatoney, M. (Ed.) *Plurality and Complementarity of Approaches in Design and Technology Education.* Apr 2015, Marseille, France. 2015, 978-2-85399-994-6. <hal-01161553> 98–105. Available from URL: https://hal.archives-ouvertes.fr/hal-01161553/document (accessed November, 2015)

de Jong, T. & Ferguson-Hessler, M. (1996). Types and Qualities of Knowledge. *Educational Psychologist 31* (2), 105–113.

Derry, S., Pea, R., Barron, B., Engle, R., Erickson, F., Goldman, R., Hall, R., Kochmann, T., Lemke, J., Sherin, M. & Sherin B. (2010). Conducting Video Research in the Learning Science: Guidance on Selection, Analysis, Technology, and Ethics. *The Journal of the Learning Sciences 19,* 3–53.

FNBE (2004). *The Finnish National Board of Education. National Core Curriculum for Basic Education* (online). Available from URL: http://www.oph.fi/download/47673_core_curricula_basic_education_4.pdf (accessed March, 2013)

Gascoigne, N. & Thornton, T. (2013). Tacit Knowledge. Durham: Acumen Publishing Limited.

Gumaelius, L. & Skogh, I., B. (2015). Work plans in technology: A study of technology education practice in Sweden. In Chatoney, M. (Ed.) Plurality and Complementarity of Approaches in Design and Technology Education. Apr 2015, Marseille, France. 2015, 978-2-85399-994-6. <hal-01161553> 188–194. Available from URL: https://hal.archives-ouvertes.fr/hal-01161553/document (accessed November, 2015)

Harris, J. & Hofer, M. (2011). Technological Pedagogical Content Knowledge (TPACK) in Action: A Descriptive Study of Secondary Teachers’ Curriculum-Based, Technology-Related Instructional Planning. *Journal of Research on Technology in Education 43* (3), 211–229.

Higgs, J. (2012). Realising Practical Wisdom From the Pursuit of Wise Practice. In Kinsella, E., A. & Pitman, A. (Eds.) *Phronesis as Professional Knowledge. Practical Wisdom in the Professions.* Rotterdam; Sense Publishers. 74–85.

Hill, A. M. (1998). Problem Solving in Real-Life Contexts: An Alternative for Design in Technology Education. *International Journal of Technology and Design Education, 8* (3), 203–220.

Hope, G. (2000). *Beyond "Draw One and Make it" – Developing Better Strategies for the Use of Drawing for Design in Key Stages 1 and 2* (electronic document). Available from URL: https://dspace.lboro.ac.uk/dspace-jspui/bitstream/2134/3391/1/Gill%20Hope%207.pdf (accessed June, 2013)

Hope, G. (2009). Beyond Knowing How to Make it Work: The conceptual foundations of designing. *Design and Technology Education: An International Journal 14* (1), 49–55.

Jones, A. (2009). Towards an articulation of students making progress in learning technological concepts and processes. In Jones, A. & de Vries, M. (eds.) *International Handbook of Research and Development in Technology Education.* Rotterdam: Sense Publications. 407–417.

Jones, A. & Moreland, J. (2003). Developing Classroom-Focused Research in Technology Education. *Canadien Journal of Science, Mathematics and Technology Education 5,* 51–66.

Leppävirta J., Kettunen H. & Sihvola A. (2011). Complex Problem Exercises in Developing Engineering Students' Conceptual and Procedural Knowledge of Electromagnetics. *IEEE Transactions on Education 54* (1), 63–66.

Lin, P.-C., Hou, H.-T., Wu, S.-Y. & Chang K.-E. (2014). Exploring college students' cognitive processing patterns during a collaborative problem-solving teaching activity integrating Facebook discussion and simulation tools. *Internet and Higher Education 22,* 51–56.

Lyle, J. (2002). Stimulated recall: a report on its use in naturalistic research. *British Educational Research Journal 29* (6), 861–878.

Marzano, R. J. (2010). When Practice Makes Perfect…Sense. Art & Science of Teaching. *Educational Leadership 68* (3), 81–83.

McCormick, R. (1997). Conceptual and procedural knowledge. *International Journal of Technology and Design Education, 7,* (1-2), 141–159.

McCormick, R. & Davidson, M. (1996) Problem solving and the tyranny of product outcomes. Journal of Design and Technology Education, 1(3), 230–241. Available from URL: http://ojs.lboro.ac.uk/ojs/index.php/JDTE/article/view/269 (accessed October, 2015)Metsärinne, M. & Kallio, M. (2014). Experiences of Classroom Techniques and Learning Outcomes. *Design and Technology Education: an International Journal 19* (3), 9–22.

Metsärinne, M., Kallio, M. & Virta, K. (2015). Pupils's Readiness for Self-Regulated Learning in the Forethought Phase of Exploratory Production. *International Journal of Technology and Design Education 25*(1), 85–108.

Mishra, P. & Koehler, M. (2006). Technological Pedagogical Content Knowledge: A Framework for teacher Knowledge. *Teachers College Record 108* (6), 1017–1054.

Mitcham, C. (1994) Thinking through Technology. The Path between Engineering and Philosophy. Chicago: The University of Chicago Press.

Parkinson, E. & Hope, G. (2009). Conceptual Learning in and Through Technology. In Jones, A. & de Vries, M. *International Handbook of Research and Development in Technology Education,* 255–264. Rotterdam; Sense Publishers.

Pezzulo, G. (2011). Grounding Procedural and Declarative Knowledge in Sensorimotor Anticipation. *Mind & Language 26* (1), 78–114.

Risatti, H. (2007). *A theory of craft. Function and aesthetic expression.* The University of North Carolina, Chapel Hill.

Ryle, G. (1949). *The Concept of Mind.* Reprinted 1969, New York: Barnes & Noble inc.

Saldana, J. (2009). *The Coding Manual for Qualitative Researchers.* London, Sage Publications.

Sahdra, B. & Thagard, P. (2003). Procedural knowledge in molecular biology. *Philosophical psychology 16* (4), 477–498.

Schneider, M., Star, J. & Rittle-Johnson B. (2011). Relations Among Conceptual Knowledge, Procedural knowledge, and procedural Flexibility in Two Samples Differing in Prior Knowledge. *Developmental Psychology 47* (6), 1525–1538.

Schooner, P., Klasander, C. & Hallström, J. (2015) Swedish teachers' views of assessing technological systems in compulsory school. In Chatoney, M. (Ed.) Plurality and Complementarity of Approaches in Design and Technology Education. Apr 2015, Marseille, France. 2015, 978-2-85399-994-6. <hal-01161553> 357–363. Available from URL: https://hal.archives-ouvertes.fr/hal-01161553/document (accessed November, 2015)

Schraw, G. (2006). Knowledge: Structures and Processes. In Alexander, P. A. & Winne, P. H. (Eds.*) Handbook of Educational Psychology.* Mahwah, New Jersey: Lawrence Erlbaum Associates, Publishers. 245–263.

Smith, E. R. (1994). Procedural Knowledge and Processing Strategies in Social Cognition. In Wyer, R. S. Jr. & Srull, T. K. (Eds.) *Handbook in Social Cognition, Volume 1: Basic Processes.* New Jersey; Lawrence Erlbaum Associates, Publishers. 99–151.

Star, J., N. (2005). Reconceptualizing Procedural Knowledge. *Journal for Research in Mathematics Education 36* (5), 404–411.

Toom, A. (2012). Considering the artistry and epistemology of tacit knowledge and knowing. *Educational Theory, 62*(6), 621-640.

Wenger, E. (1998). *Communities of Practice: Learning, Meaning and Identity*. New York: Cambridge University Press.

Yin, R. K. (2006). Case Study Methods. In Green, L., Camilli, G. & Elmore, P. (Eds.*) Handbook of Complementary Methods in Education Research.* Mahwah: Lawrence Erlbaum Associates, Publishers. 111–122.

Yin, R. K. (2009). *Case Study Research. Design and methods (fourth edition).* Thousand Oaks, CA:Sage.