

Design and Technology Education: An International Journal



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Guest Editorial

Talking and Understanding Technology in the Primary setting

Wendy Fox Turnbull, Waikato University, New Zealand
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In recent years technology education has taken a backward seat in primary schools as governments push for evidence that money spent on education is making a difference. Rightly or wrongly, the measure of such difference was equated to skills and abilities in the areas of literacy and numeracy. Unsurprisingly to many the results of such initiatives have been underwhelming to say the least. Those in the fields of technology, science, social sciences have always advocated for an interdisciplinary approach to integration in which these subject or learning areas become the catalyst for the development of literacy and numeracy skills in authentic, student-centred contexts, along with a range of other skills necessary to flourish in a current and future world.

We therefore believe that the time is right to offer a special featured section of Design and Technology Education: An International Journal, devoted to technology education in primary schools. Two broad themes emerge across the six articles in this special section. The first is classroom talk and the role it has in students' learning in technology and understanding that learning from teachers' perspective'. The second is related to cultural norms and behaviours, namely gender and indigenous cultural technologies.

Classroom talk, oral language and explanation link three articles in this edition. In their article Swathi RR, Wendy Fox-Turnbull, Kerry Earl-Rinehart and Nigel Calder (Waikato University, New Zealand) report on research undertaken on the development of a tool to assist teachers' teaching skills and knowledge and their understanding of technology education. The value of classroom interaction is at the core of this article. It reports on the continued development of the Technology Observations and Conversation framework originally developed to assist teachers' understanding of technology learning for young students aged between four and six years of age. In the research reported in this article, this framework was modified to suit the New Zealand context and to be more effective for students nine to ten years of age. The iterative nature of the process used to modify the framework was teacher informed. The study illustrates how having specific questions to ask their students assisted teachers' thinking in technology. An especially concerning issue highlighted in the article is teachers' lack of understanding and experiences teaching technology.

In their article, Hanno van Keulen and Conny Boendermaker (Windesheim University of Applied Science, The Netherlands) also focus on communication, language development through science inquiry and technology design and make approaches. This article too has a focus on student oral language with an emphasis of offering a science and technology context to engage the students in quality talk. This same context was also used to motivate reading with topic related age-appropriate books with the aim of improving reading levels, thus illustrating the

point made in the introductory paragraph about the value of technology as a “vehicle” for learning in other learning areas. Integration and authenticity are at the heart of this article. During the study teachers improved their asking of questions and their ability to facilitate conversation as well as giving students context related reading. This study concludes that successful teachers still need considerable encouragement and a Professional Learning Community (PLC) to manage the perceived risk of change - movement away from structured textbook related reading tasks to reading tasks in authentic contexts related to the student’s inquiry into the natural and technological world.

The article by David Mioduser and Asi Kuperman (Tel Aviv University, Israel) is a standout article for its investigation into how very young children (5-8 year olds) explain behaviour of robots. Again, we see the oral language plays in this process. This research investigates three groups of children who are taught to either programme a robot doing various tasks, or observe such robots and explain their behaviour. The research offers fascinating insight into how children explain robots’ behaviours as scripts, episodes, or rules. The children who programmed the robots tended to think of the robot’s behaviour in terms of rules. This finding offers concrete evidence that introducing programming in kindergarten curriculum could be advantageous to children.

The second broad theme in this journal related to cultural norms. In their article, Milorad Cerovac, Kurt Seemann and Therese Keane (Swinburne University of Technology, Australia) report on a pilot study on spatial reasoning in primary school students, finding difference related to gender when working in a group. The role of gender is discussed as being important when examining key cognitive functions such as spatial inferential reasoning. During the study reported in this article, the young participants recognised gender-related stereotypes. This raises implications for teachers. How are gender stereotypes avoided at the primary level, especially in light of the under-representation of women in technology? This study also provides some understanding of gender differences in collaborative group work in technology. Girls collaborated more than the boys and tended to remain on task and less distracted than the boys. This article also highlights self-esteem issues students face when given a complicated task where they “fail”. These findings will be further developed in a larger study that is planned for the future. The initial findings, though, highlight emerging understanding and need for further research in spatial reasoning especially in relation to gendered differences.

Gender is still the main theme in an article from Ulrika Sultan, Cecilia Axell and Jonas Hallström (Linköping University, Sweden), which contradicts Cerovac, Seemann & Keane’s findings about girls leading collaborative tasks. They instead identify girls’ reluctance to engage in technology. Examining self-image of 9-12 year old girls, the research reported in this article found that girls did not lead the task in mixed-gender groups. This paper additionally deals with girls’ identity in relation to technology and provides insight into possible reasons girls lose interest in technology as they grow older. This article suggests that despite the teacher introducing gender-neutral activities as suggested in previous research, the girls in the study were conflicted about their self-image as technologists. They approached boys for help with “technical” tools and did not seem to recognise the tools they were skilled at using as “technology”. It is also interesting to note that girls seem to accept the stereotypes associated with technology and females and also in some sense promoted the stereotype actively in the

classroom by feeling and acting helpless in their choice of tools and level of engagement with the tasks.

In technology cultural-related stereotypical ideas are not limited to gender, but also include ideas about indigenous technologies. In her article Cecilia Axell (Linköping University, Sweden) presents a case study carried out in a Sámi school in Sweden. Sámi are indigenous to Sweden. The aim of the study was to understand the use of indigenous artefacts in technology teaching. The paper describes three very interesting lessons taught in a classroom with eight and nine year old children related to three indigenous technologies. Learning about the indigenous artefacts helped create a link between past and present and deepen technological knowledge by presenting the artefacts as a solution to problems faced by the Sámi people using the existing resources. Indigenous technology also have a role to play as symbolic artefact contextualised through myths and storytelling. This paper offers interesting ways in which indigenous knowledge can be incorporated into technology lessons in authentic and meaningful ways thus distilling stereotypical views of indigenous technologies.

In conclusion, it is interesting to note the comment in Axell's article about the relationship between indigenous technologies and their contextualisation through myths and storytelling. We complete the circle and return to the power of oral language in technology. Oral language enables a voice to students who have trouble writing and drawing their ideas. It is a valuable tool for teachers to engage with, challenge, learn about and from their students and finally it gives life and voice to technologies from indigenous cultures with strong oral traditions.

Development of formative assessment tool for a primary, technology classroom

Swathi RR, University of Waikato, New Zealand

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Abstract

Teachers and students' interactions in the classroom include a large number of questions, some of which are a key part of formative assessment. Questions can lead to an extended dialogue between the teacher and the student, potentially facilitating a better understanding of the students' conceptions and providing teachers with information to guide student learning. Technology Observation and Conversation Framework (TOCF) was identified as a framework of questions specially designed for a technology classroom. In this qualitative, design-based research, the TOCF was modified for alignment with the New Zealand curriculum and provided to two primary teachers teaching ages 9-10. The version of TOCF reported in this article was developed through an iterative process in an authentic environment. The teachers were interviewed periodically, and modifications were made to the format of the framework. The findings in this paper focus on the outputs of the iterative process and the feedback given by the teachers on the TOCF. While teachers in the study found the questions crucial to deepen student thinking in technology, they faced some constraints in using the TOCF in the classroom. The findings suggest that any introduction of a new resource should proceed slowly in the classroom and time needs to be given for increasing familiarity with the new resource. It is also possible that inexperienced teachers could find adoption of questioning practice quite tricky and would need to be supported extensively to change their practice.

Keywords

Technology education, design and technology, higher-order questions, teacher change, questioning, formative assessment.

Introduction

Questions are ubiquitous in our daily interactions as well as in the classroom. There is increasing understanding in literature and classrooms that questions should be the starting point of a dialogue. The purpose of these dialogues in the classroom could be for teaching, learning or assessment, especially formative assessment. Formative assessment carried out in the interaction between teacher and students could assist the teacher in deciding the direction of learning for the students. Formative assessment is linked to substantial learning gains (Black & Wiliam, 1998).

This paper draws from a more extensive qualitative study that looks at the interactions in the technology classroom and their influence on teachers and students' learning in middle primary classrooms in New Zealand. These interactions begin with questions from a planned framework of questions for technology education – Technology Observation and Conversation Framework (TOCF) developed by Fox-Turnbull (2017, 2018, 2019), which is used as a formative assessment

tool in this study. The scope of this paper is limited to describing the iterative process of the development of the TOCF and the feedback from the teachers about the TOCF.

Interactive formative assessment and questions

In this study, formative assessment is defined as "the process used by teachers and students to recognise and respond to students' learning in order to enhance that learning, during the learning" (Cowie & Bell, 1999, p. 101). Interaction is one way for teachers to formatively assess the students in real-time since the teacher can listen for any gaps in student learning and provide immediate feedback (Bell & Cowie, 2001; Clarke, 2008; Ruiz-Primo, 2011). Cowie and Bell (1999) called formative assessment carried out in interactions as interactive formative assessment and explained that this assessment is informal, unplanned, transient, and usually student-referenced and criterion-referenced.

Asking questions is a crucial part of interactive formative assessment (Bell & Cowie, 2001; Kawalkar & Vijapurkar, 2013; Ruiz-Primo, 2011; van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001; Wiliam, 2011). The quality of a teacher's question can influence the quality of student thinking (Fordham, 2006; Smart & Marshall, 2013; Wilen, 1991). Good questions can be used to diagnose students' ideas, extend their thinking and to scaffold their learning (Chin, 2007; Jacques, Cian, Herro, & Quigley, 2019; Roth, 1996). Different questioning approaches can aid the teacher in shifting the responsibility for learning to the student (Jacques et al., 2019). Despite the pervasiveness of questions in a classroom, few research studies deal with a fine-grained analysis on questioning practices (Chin, 2007; Hill, 2016; Roth, 1996) and find teachers who ask good questions in the classroom (Myhill, 2006).

All types of questions have a role to play in the classroom (Alexander, 2004). However, research and classroom experiences have shown that factual/recall questions are typically answered in a few words (English, Hargreaves, & Hislam, 2002). Limited contribution on the part of the students is a problem since it has been shown that focused, sustained discussion amongst students helps with their learning process (Alexander, Hardman, & Hardman, 2017; Howe, Hennessy, Mercer, Vrikki, & Wheatley, 2019; Mercer & Littleton, 2007). This paper focusses on questions that lead to a dialogue between the teacher and student/s and hence, simple factual or recall questions that are typically answered in few words are not the focus of this study.

Questions are cues for beginning a dialogue between the teacher and the student (Lemke, 1990). Hall and Burke (2006) accurately summed up the importance of discussions in stating, "Meanings and interpretations are co-constructed through discussion and activity" (p. 8). Discussion and dialogue have the highest cognitive potential for the student of all types of talk in the classroom (Alexander, 2004). Through open discussion and dialogue, teachers or other students in the class can provide scaffolding for developing ideas that can lead to powerful learning experiences (Alexander et al., 2017; Applebee, Langer, Nystrand, & Gamoran, 2003). In teacher-student dialogue, teachers need to ask authentic questions and ask for further elaboration, clarification and build on the previous contribution to truly benefit student learning (Howe et al., 2019).

It has been suggested that good questions need to be pre-planned to provoke thought and sustain dialogue (Shavelson, 2006; Wiliam, 2011). Good questions need to be carefully thought

out and shared among different teachers (William, 2011). Without a repertoire of good questions, teachers could settle for asking recall or factual questions (Jacques et al., 2019).

A planned framework of questions

The Technology Observation and Conversation Framework (TOCF) developed by Fox-Turnbull (2017, 2018) is designed for technology classrooms and provides a guide to the teacher for things to notice, conversation cues, and higher-order questions that develop students' learning in technology. It was designed based on research on classroom talk, 21st-century skills and dispositions and technology aims across multiple countries. This version of TOCF was designed for early childhood and early primary students up to the age of six.

TOCF is presented as a table and the complete TOCF are present in the appendix of the published journal articles (Fox-Turnbull, 2017, 2018, 2019). The rows are the **technology aspects** derived from various global technology curriculums and columns are **behaviours in technology**. The **technology aspects** are Understanding of/exploring the technological (made) world, evaluating current technologies, identifying technological problems or needs, designing and making technological outcomes to meet the needs and understanding key concepts of technology and deploying them in practice. The five behaviours were defined based on the work of Claxton, Chambers, Powell, and Lucas (2011) and 21st-century skills and they are resilience, transference, sophistication & flexibility, reflection and socialisation (defined and explained in Table 1).

Table 1 *The five behaviours and what they include*

Term	What it includes
Resilience	Resilience includes capabilities of perseverance, especially after an initial failure, managing distractions from peers, other activities and people around them, and absorption in any given task.
Transference	Transference included making links to technologies experienced or seen, and experiences undertaken previously, such as using existing cultural knowledge and experiences or Funds of Knowledge. It also included imagining how existing knowledge and skills might be transferred to new situations.
Sophistication and Flexibility	Flexibility and sophistication indicated an increased depth of understanding, as well as an openness to new and potentially strange ideas. Embedded in this behaviour were reasoning and distilling information aimed at assisting understanding and questioning of others. Planning ideas, actions, and making the best use of resources also characterised this behaviour.

Reflection	Reflection described the strategic and self-managing aspect of learning including the planning and anticipation of needs and issues, distilling information for potential use, revision of prior learning and identification of learning that can be transferred to a new context, self-generated questioning and monitoring progress through cognisance of what, how and why learning occurs.
Socialisation	Socialisation is important due to the inherently social nature of technology practice and the physical, social and environmental impacts of technology. Whether engaged in the use of, or development of technological outcomes, students interacted in a social manner. Through collaboration with others, students experienced interdependence with a balancing of self-reliance and socialisation.

Note: Terms and explanation from Fox-Turnbull (2018)

The cells of the table have a series of observation markers, higher-order questions and suggested teacher comments on student technology practice. Some examples of questions are:

- If you/they were to redo this or make improvements, what changes should you/ they make? Why? (Strand: Technological practice and Behaviour: Reflection)
- What ideas did you change after talking to X/group? (Strand: Technological practice and Behaviour: Socialisation)
- What have we already learned that will help us with this design? (Strand: Technological knowledge and Behaviour: Transference)

The TOCF aimed to enhance technology teachers' pedagogical content knowledge and content knowledge and inform their "formative understandings of students' learning in technology" (Fox-Turnbull, 2018, p. 4). It aimed to develop these understandings by facilitating quality teacher-student interactions.

Fox-Turnbull (2018) used her TOCF with teachers teaching with 5-8-year-olds across three countries – New Zealand, England and Sweden. In the qualitative study conducted by Fox-Turnbull with six teachers, the participants stated that the framework helped them in developing a deep understanding of technology and technological practices. It helped them to support students to think at a higher level. The participants recommended that the TOCF be offered during the planning stage and commented that while it was time-consuming to become familiar with the TOCF, it could prove to be worth it (Fox-Turnbull, 2017). The teachers also wanted a more easy-to-use format for quick reference in the classroom. Some of the participants commented that some contextualising of the questions could prove beneficial (Fox-Turnbull, 2017).

TOCF was reviewed for the purpose of a formative assessment tool for this research. The findings about its use as a formative assessment tool will be discussed elsewhere. In this study,

the main change needed was to extend the TOCF to a higher age group for carrying out the research in primary classrooms in New Zealand (NZ). In NZ, up to Year 6, generalist classroom teachers typically teach technology (Ministry of Education, 2016) which corresponds to age 10. Hence, it was decided to extend the TOCF up to this age group. It was also decided to contextualise the research to the New Zealand Curriculum (NZC) – the exact changes are described in the next section.

New Zealand and technology curriculum

New Zealand curriculum aims to develop young people to be confident, connected, actively involved and lifelong learners (Ministry of Education, 2007). With a view to fulfil the vision, the NZC stresses key competencies to be incorporated in all lessons in the school day. These key competencies are thinking, using language, symbols and texts, managing self, relating to others, and participating and contributing (Ministry of Education, 2007).

Technology education is a mandatory learning area in the NZC taught to students from Year 1 to Year 10 (age 5-14) and non-mandatory from Year 11-13 (age 15-17). Technology is defined in the New Zealand Curriculum (NZC) as "intervention by design: the use of practical and intellectual resources to develop products and systems (technological outcomes) that expand human possibilities by addressing needs and realising opportunities" (Ministry of Education, 2007, p. 32). New Zealand introduced technology education as a mandatory learning area (Year 1-Year 10) in 1995 and implemented it in schools by 1999. The curriculum has changed twice since 1999 - in 2007 to change the strands and technological areas and again in 2017 to introduce digital technologies and computational thinking. The latest changes in the curriculum came into effect from the beginning of 2020.

Teachers teach technology across multiple technological areas – digital outcomes, material outcomes (textile, resistant materials like wood, metal, etc.), process outcomes (food, biotechnology), and design and visual communication (DVC). Within the technological areas, students design outcomes across a range of authentic contexts and broad issues. These design outcomes could be as diverse as designing a recipe book, making a skateboard, designing props for school plays, designing websites or apps to solve local problems, etc. In addition to providing an experience of authentic technological practice, teachers teach specific skills (like 3D modelling, woodworking, soldering, etc.) that students need to be able to design and make their technological outcome.

In the NZC, technology education is taught through three strands - technological practice, technological knowledge and nature of technology. Students are exposed to authentic technological practice while also being exposed to the implications of technology in society. While not all three strands need to be introduced in every single lesson, it is expected that a unit of technology have elements from every strand (Ministry of Education, 2018). The different strands and its components are shown in Figure 1.

In the NZC, technology is taught through eight levels. The student outcomes at each of this level are documented in the 'Indicators of Progression' (IoP) that can be used to evaluate the students' learning in technology (Ministry of Education, 2018). Teachers teaching technology have to integrate the student outcomes that are described in the IoP and the key competencies, in every technology unit.

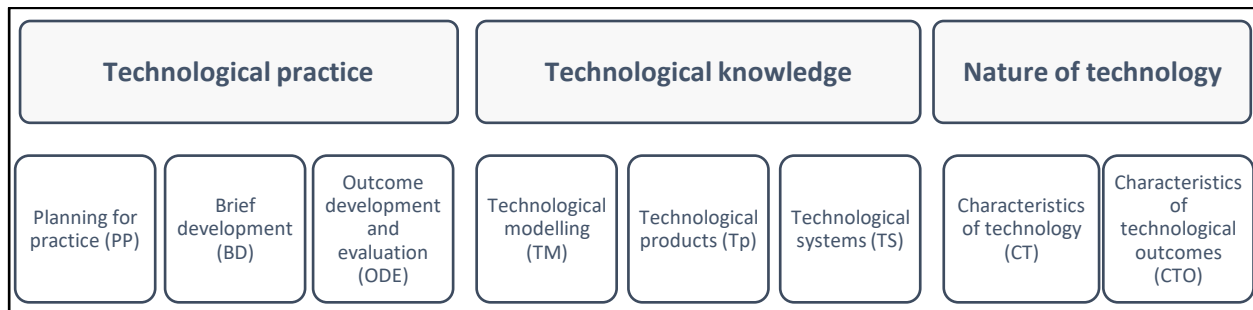


Figure 1: Strands and components of technology education mentioned in the NZC
Adapted from *Technology in the New Zealand Curriculum* (p. 5), by Ministry of Education, 2018.

Methodology

This qualitative study follows the ontological stance of pragmatism, as proposed by John Dewey. The conclusions from a single context in Deweyan pragmatism are not generalizable (Biesta & Burbules, 2003). The methodological framework, known as design-based research (Bakker, 2018), aligns with the pragmatic paradigm and is an appropriate approach since the aim in this research is to design/ develop a tool for use in the classroom in a naturalistic environment.

Design-based research

The term "design experiment" was coined by Ann Brown and Allan Collins in the 1990s (Collins, Joseph, & Bielaczyc, 2004). Design experiment is synonymous with design research or design-based research as it is called in more recent publications (Barab & Squire, 2004). It is a strong belief in design-based research that the context matters in terms of learning and cognition and cannot be considered as a variable or set of variables (Bakker, 2018; Barab & Squire, 2004; Collins et al., 2004; The Design-based research collective, 2003). Due to the importance of the context of research, design-based research is carried out in a naturalistic environment (Bakker, 2018). Design-based research aims to investigate an issue or implement an intervention in a specific context through multiple iterations and collaboration between the practitioner (teacher) and the researcher (The Design-based research collective, 2003).

In this study, as two teachers attempted to use the TOCF in the classroom, the format of the TOCF was changed iteratively to develop the TOCF. These rounds of iterations were first carried out with one teacher considering the participant availability. After multiple iterations, the second teacher used the developed TOCF and gave further comments. These iterations and outputs from the iteration rounds are the main findings reported in this paper.

Background of participants

This study was conducted with two primary teachers teaching Years 5 and 6 (9-10-year-old) in an urban area in New Zealand. The two primary teachers - Jean and Sarah-Jane (both pseudonyms) are from New Zealand. Jean had three years of teaching experience, and Sarah Jane was in the 15th year of teaching at primary school. Jean had 26 students in the class, and Sarah-Jane had 30 students. Over 18 weeks, a total of around 150 hours was observed in Jean's class and around 16 hours in Sarah Jane's class – this depended on the context of the

classrooms, availability of the teachers and the teacher's plan for delivery of the technology lessons.

Jean and Sarah-Jane had limited experience in teaching technology. In the initial interview, both informed that they had limited knowledge of the technology curriculum. However, they seemed well versed in the design process and understood its iterative nature. Both considered the design process as key to student motivation and engagement in the classroom and designed their lessons around the design process.

Methods

Ethics was obtained from the University of Waikato. Consent forms were signed by the Principal, teacher, parents and students and pseudonyms have been used for schools, teachers and students to protect confidentiality.

The teacher interviews and observation notes are the primary evidence source. The teachers were interviewed before the technology unit began and periodically through the unit. All the interviews were transcribed using online software, checked and sent to the teachers for member checking. The first author did the data collection, observed the classroom and took detailed notes. The notes had information on the teacher and student actions in the classroom through the observation period. Both the teachers wore an audio recorder when they delivered the technology lessons, and these audios are used to triangulate the findings.

The modification of the TOCF was discussed amongst all the authors on an ongoing basis. The interview transcripts and classroom observation notes were read multiple times before starting the coding process. Some initial quotes and findings were discussed amongst the authors. The interviews were then coded in NVivo. For this paper, the interviews were coded for specific mention of the TOCF framework and these were further coded as feedback on the framework and constraints on using the TOCF. Classroom observation notes were studied multiple times, and instances of development and use of the framework were identified. In case there were any gaps, the teacher audios were used to triangulate the findings. The findings were discussed amongst the authors, and the coding and findings were rechecked and confirmed from the data once again.

Findings

The findings for this paper are focussed on the development process of the TOCF. There were four rounds of iterations. The numbers of rounds were based on participant availability, and each iteration had a specific output at the end. These rounds are described in detail, below.

Iteration Round 1

This iteration round occurred before any classroom observation and focussed on revising the TOCF for use in this study. The original TOCF had observation cues and comments that the teacher could make in a technology classroom. However, these were not the focus of this study, and hence the first modification was to focus only on the questions.

The context of this study is New Zealand primary classrooms. In the NZC for any learning area, progressions and strands are described and teachers are familiar with the concept of strands and levels for progression. Hence, the TOCF was modified to align with the strands from the

NZC technology curriculum and it was decided to have questions at different levels of progression in alignment to the IoP of technology. The benefit of doing this was to familiarise teachers with the IoP as the NMSSA survey (Ministry of Education, 2016) indicated that only a small minority of primary teachers in New Zealand know the Indicators of Progression (IoP). Considering that the target age group was ten, it was planned to develop the TOCF up to the level appropriate for this age group – Level 3 (Ministry of Education, 2007). An additional level – Level 4 was added so that teachers could see the progression for the next level so that they had the option of preparing students for a higher level.

Aligning the TOCF with the NZC and IoP increased the number of questions. The earlier framework had 91 questions and was created for early childhood and early primary students. The modified TOCF had 252 questions and could now be used for students from ages 5-12 (Year 1 to Year 8). The purpose was to provide for students in a wider age range and align it with progression levels 1-4 from the IoP. As it was recognised that 252 is a large number of questions, it was decided to change the look and the format so that teachers would not be overwhelmed with the number of questions. It was decided to cluster the strands such that the teacher would need to access, review and read a limited amount of questions in each lesson.

Characteristics of Technology (CT) and Technological outcomes (CTO)/ Research phase/ Tuning in, finding out about similar technologies		
<p>Reflection</p> <p><u>Level 1</u></p> <ul style="list-style-type: none"> What are the main tasks for a technologist (a person who designs stuff)? What do you think about when you use this technology? <p><u>Level 2</u></p> <ul style="list-style-type: none"> What knowledge have you learnt by studying this product? What (part/ feature) in this technology was a new learning for you? What did you notice about the way that works? 	<p>Sophistication and flexibility</p> <p><u>Level 1</u></p> <ul style="list-style-type: none"> What are the benefits of <i>this feature/ this design</i>? Of the following which are technology: tree, computers, hammer, birds, bird nest, pen, book, bread, shirt? What makes this technology safe to use? Who do you think this technology is made for? <p><u>Level 2</u></p> <ul style="list-style-type: none"> What is successful about <i>this technology</i>? What is not good about it? How do you think <i>this technology</i> was developed through the time? How do you think <i>this technology</i> changed the way we live? Can you name some technology that has helped (or not helped) the society? Tell me why <i>this technology</i> is technology How does technology having X feature help it do its job? What would a 'bad' technology look/ sound/ smell/ taste/ feel? How else might this technology be used? What makes this product a good design? What features in this technology make it safe to use? 	<p>Socialisation</p> <p><u>Level 1</u></p> <ul style="list-style-type: none"> Who makes stuff (technology)? Why do you think that? <p><u>Level 2</u></p> <ul style="list-style-type: none"> What groups of people will like this technological outcome best? Who will not like it? What do you think Mum or Dad (or another important person in their lives) would think of this? Would they use it? Why do you say that? What would you like to ask the person who made this to find out about how and why it works? Do you have the same or different ideas about this technology than your parents? Why? How is X feature in this product showing that it is designed for Y person? What makes you say that?
<p>Transference</p> <p><u>Level 1</u></p> <ul style="list-style-type: none"> Have you seen this feature in something else? <p><u>Level 2</u></p> <ul style="list-style-type: none"> What do you know about recognising a technology problem from doing technology in school another time? What are some things about <i>this technology</i> that you can use for your design? What have we already learned that will help us with this design? 		<p>Resilience</p> <p><u>Level 1</u></p> <ul style="list-style-type: none"> Do you think it was an easy job to design this? Why do you think that? <p><u>Level 2</u></p> <ul style="list-style-type: none"> How long do you think this technology took to design and make?

Figure 2: Iteration Round 1 output

Based on authentic technology practice and therefore, chronological use in the classroom, the strands were clustered in the following manner:

The nature of technology: Characteristics of Technology and Characteristics of Technological Outcome (CT and CTO)

- Technological practice: Brief development and Planning for practice (BD and PP)
- Technological practice: Outcome Development and Evaluation (ODE)
- Technological knowledge: Technological Modelling and Technological products (TM and Tp)
- Technological knowledge: Technological Systems (TS)

Each of the above clusters was split into separate sheets. Each sheet had all five behaviours. Every cluster had two pages – one for Levels 1-2 and the other for Levels 3-4.

In any one lesson, teachers may need to refer to up to two pages based on what the students are doing in that lesson. This workaround was conceived with the logic that teachers would look at very few questions in each lesson but still have a bank of questions for their use for multiple age groups or multiple years with the same group of students. Each page could have up to 32 questions. Each of the five behaviours was put in a different colour box so that visually, it was easy for the teacher to refer to a specific behaviour in their questioning. An example of the Nature of technology sheet Level 1-2 can be seen in Figure 2.

However, considering the classroom experiences of the researchers, it was noted that 32 questions could still be overwhelming for a teacher. In the initial interview, the teachers were asked to focus only on couple of behaviours for a unit of technology so that the number of questions that they needed to refer could be reduced to 6-12. The choice for the behaviours would be based on what teachers perceived as important for their students.

Iteration Round 2

The modified TOCF provided to the teachers was in the form of nine coloured sheets. Both teachers were shown this format and all nine sheets in an initial interview. In the interview and through initial classroom observations, it emerged that the teachers were unfamiliar with the strands of technology. Hence, the titles were changed to reflect more familiar phrases that were in use in the classroom. For example, additional titles for CT and CTO sheet was "Research phase" and "Tuning in" and "Finding out about similar technologies".

Jean used this format in the classroom first. After the first week of observation, it was observed that Jean was unable to use more than 1-2 questions through the week except at the end of the week when she used the TOCF to pick out weekly reflection questions for the students. For the first two weeks, the researcher assisted her in picking these questions for reflection as she found it difficult to find questions from the TOCF.

In consultation with Jean, the researcher decided to temporarily select a few questions and put them on one sheet to support Jean to ask more questions in the classroom. This iteration of the framework was to make Jean comfortable and was not considered as a modification of the main framework. The plan was to go back to the original framework and modify it in such a way that it was easier to find questions. While the researcher worked on a more accessible TOCF version, the modification shown in Figure 3 was a temporary fix.

Jean worked on a different component of technology every day. Accordingly, the questions were picked from different components and were mainly from the behaviour "sophistication and flexibility". As Jean found it difficult to ask all students and keep track of different students'

progress, a student checkbox was added so that Jean could track the students to whom she asked questions. This single sheet of questions was in a physical form that Jean had to carry around in the class.

Monday: Tuning in, finding out (4 concepts by end of the day)

- What are the features of your design? Why do you need these features?
- How did you decide on these features?

L3: Ask anyone who says they are done

- What else could you add to the list of features to make your end product better?
- What are some properties (features) of this material? How do these properties help with your design?

Tuesday (Market research)

- What features are the most important to your customer? Why?

Wednesday (Finalisation of design)

- What is your plan to make the product? What are the key steps?
- What materials do you need?

L3: Ask anyone who says they are done

- What materials do you need at each stage?
- How will you test/evaluate your outcome?
- How have you used your customer's voice in your plan?

Name	Mon	Tue	Wed
Olivia			
Ruby			
William			
Noah			
Vivian			
Leo			
Rian			
Ruby			
Mia			
Harper			
Ava			
Willow			
Lucas			
Amelia			
Sophie			
Nicole			
Leo			
George			
Dev			
Isla			
Emily			
Brooke			

Thursday: Making the product

- How is the final product in line with your drawing? How is it not?
- Why did you make changes to your design while making it?
- What are the best parts of your product?
- What are the not-so-good parts of your product?

Friday: Reflection

- Check your initial list of features. How does your final product meet them?
- What was easy in making this product? What was difficult?
- What will you do differently the next time in making a product?

Monday/ Tuesday: Logo design and advertising material

- What do you like best about this logo/promotional material?
- How does this (logo/promotional material) address your customer's needs?

L3

- What groups of people will not like this logo/promotional material?

Name	Mon	Tue	Wed
Olivia			
Ruby			
William			
Noah			
Vivian			
Leo			
Rian			
Ruby			
Mia			
Harper			
Ava			
Willow			
Lucas			
Amelia			
Sophie			
Nicole			
Leo			
George			
Dev			
Isla			
Emily			
Brooke			

Figure 3: Iteration Round 2 output

Iteration Round 3

Jean used the above modification as much as she used the full version. Only in one instance she sat down with the actual physical sheet and asked four groups of students, questions from the TOCF. She continued to use the TOCF for reflection questions at the end of the week.

In the two weeks that Jean used the temporary modification, the first author in consultation with the other authors changed the format of the framework. As the main trouble was the number of questions in one sheet, the framework was split into multiple small cards, each having 5-7 questions. Only 2-3 "Flexibility and sophistication" cards contained around 7-12 questions. Each behaviour and each strand were separated into a card. The long bulky titles were modified to something short and generic, and the full title was placed at the back of the cards to ensure retention of meaning. All these cards were put in a ring holder so that they could be flipped through easily or removed if the teacher was not interested in individual cards. Example of these cards can be seen in Figure 4.

Jean was offered this format for the final two weeks of observation. While Jean used this format as much as the other formats, she found it easier to look for questions for reflection on her own and did not need the researcher support to look for questions. Her independence with using the TOCF could also be due to growing familiarity with the TOCF.

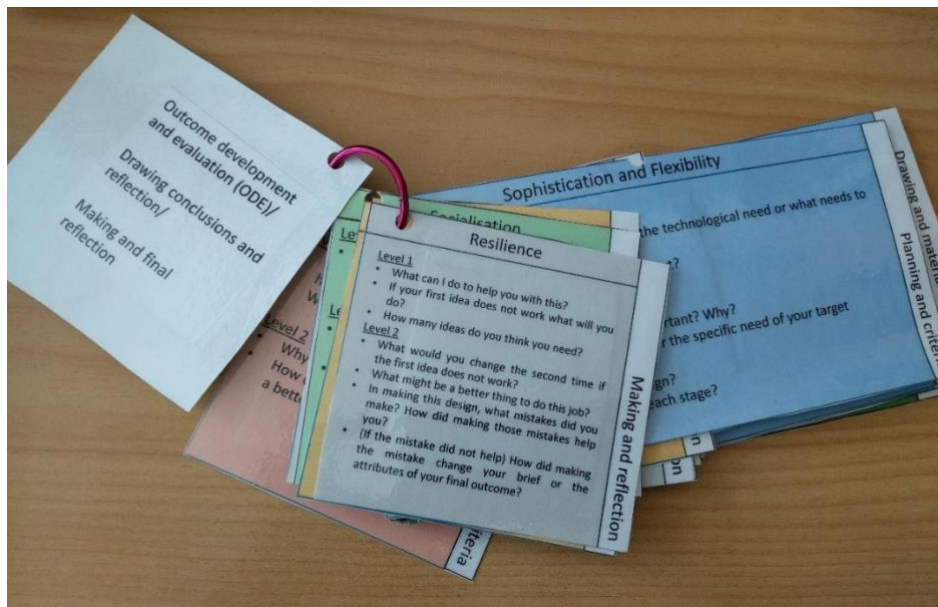


Figure 4: Iteration Round 3 output

Iteration Round 4

The output from iteration round 3 was given to the second teacher – Sarah-Jane who commented that there were too many questions, and it was quite complicated. After the observation of the first lesson in the unit, she mentioned again that it was overwhelming to use the TOCF, and in response to this comment, she was offered only four cards. The plan was to add more cards as she got comfortable with using the framework. The four cards were chosen based on what she was planning to focus during the unit and the behaviours she had chosen - Level 1-4 of TM-Tp and ODE on the behaviour "Sophistication and Flexibility". Once she was comfortable using this in the class after four lessons, "Reflection" cards from Level 1-4 for the same components were added. She mentioned in the interview that "I have read them (the cards) more than once now. So that's probably subconsciously here" (T2_15_Line 81).

After one week of handing over the "Reflection" cards, the data collection ended, and the iteration rounds stopped.

Feedback on the modified TOCF

Through the development process, both teachers gave extensive feedback on the TOCF. The findings in this section refer to the teachers' comments and are organised into two main themes: general feedback on the TOCF and constraints in using the framework. Both teachers had different experiences with the framework, and these will be explained in detail, below.

General feedback of TOCF

Both teachers felt that having the framework in the planning stage was helpful. The usefulness of the framework for teachers in the planning stage was also mentioned by the participants in the previous study (Fox-Turnbull, 2018). Both mentioned that they were unfamiliar with Technological Systems (TS). Sarah-Jane commented that she did not like the Level 3-4 questions of socialisation. She felt that her students would not be able to relate to the questions at that level of socialisation. In contrast, Jean commented that the socialisation questions were "especially good".

Both the teachers were mainly positive about the questions. Jean commented several times that "I love the questions. Like I really think they are so effective and every time I read them, I thought these are really good" (T1_I7_Line 448). Sarah-Jane commented "You know, if you are not asking those (higher-order) questions, you are not getting them to think better or build on their understanding" (T2_I5_Line70). Jean shared these questions with the other senior primary classes, and during the final interview commented that the questions helped multiple classrooms and all other teachers were impressed with these questions as well.

Sarah-Jane felt that the framework was more of a "teacher-guide" and not for students due to the language. She modified the questions when asking them to the students. One example of modification Sarah-Jane mentioned in the interview was to modify a Level 3 question from "Why did you choose to make X and not Y plan?" to "Why have you chosen this design?" (while pointing to the students' designs).

Both identified that the framework was focussed beyond technical concepts and included attention to the key competencies in the NZC. Jean also mentioned that TOCF inclusion of the behaviours of socialisation and reflection made her feel valued about what she was doing in the classroom. She commented that she knew that her school and she personally valued these behaviours but "seeing it on paper that they are valued by researchers is nice and kind of affirming" (T1_I3_Line33).

Constraints with using the framework in the classroom

Both teachers felt that there were too many questions, and it was overwhelming to read them all together. They also felt that many questions were not age-appropriate. Sarah-Jane was particularly disappointed with the language – she commented multiple times in the initial interview that some of her students would not understand the language of the questions even at the lowest level. Both teachers commented that there were questions in the framework that they could not answer.

While commenting on the use of the framework in the classroom, Jean felt that due to her habits, she would have to change something drastic to be able to use the framework in the class. On the other hand, Sarah-Jane did not express any concerns about using the framework in the classroom since she said she was used to questioning.

Jean did not use the framework in every lesson, even when she was asking questions about students' designs or technological practices. She said that she did not know the questions "off the top of my head" and she found it difficult to carry any paper around. Jean felt that reading the TOCF multiple times was not a good use of her time. While her comments about the TOCF were positive, and she seemed genuinely excited about the questions, she mentioned that her priority was reading, writing and maths. In contrast, Sarah-Jane used the framework in every lesson, as evidenced in the audio recordings and observation notes. Sarah-Jane mentioned that she had read the framework multiple times and that they were in her "subconscious".

Discussion

As the findings section describes, the different iterations were fuelled by teacher feedback on the framework both explicitly and from class observations. Through the design process, the

idea was to make using the framework easier in the classroom for busy teachers who may not have time to go through big sheets with lots of text.

Although it had been explained to both teachers in the initial interview to use only 1-2 sheets in the classroom at a time, the teachers found it overwhelming just to read all the questions and become familiar with them in the initial iteration formats. The earlier motivation for showing the complete framework with 252 questions was to get feedback on them. In retrospect, it can be seen that it may have been beneficial to only introduce a few questions at a time even for feedback. Researchers' priorities differ from the teachers' priorities in the classroom. Researchers need to remember that since they are comfortable with their tools due to the length of our exposure during development, it is not the same for teachers for whom this is not the top priority in the classroom. The design-based research process in this framework development reinforced that it is important to go very slowly with the introduction of new tools in the classroom even if the tools are something the teacher may already be using in their practice.

Jean, an inexperienced teacher, found it difficult to ask questions to everyone in the classroom and also remember the different students' response to guide their actions beyond that moment. She mentioned that her "working memory was full". Jean knew that the answers to the questions could guide her understanding of the student learning process, but to do that for 26 students in the class was overwhelming to her. In response to a different question at the end of a cycle about the design of two girls in the classroom, she did not recall the conversation she had with them which caused them to change their design. She tried to note down comments on a paper and on her computer through the unit, but this was not practically possible every day. These findings support research that shows that inexperienced teachers have lesser recall of classroom memories than experienced teachers (Peterson & Comeaux, 1987) and that they feel overwhelmed (Kim & Klassen, 2018). Novices, in general, exhibit limited processing capacity that constraints learning and performance (Paas & Van Merriënboer, 1994).

In contrast, Sarah-Jane was an experienced teacher. She did not express feeling overwhelmed at asking questions or using student responses to guide her next steps. She felt more in control of using the framework in the classroom and of the cards given to her, she referred to them frequently and asked the questions as is evident from the classroom observations.

Jean's priorities in the classroom also proved to be a constraint in the adoption of the TOCF. As mentioned before, Jean felt her main priority was reading, writing and maths and the technology part was not a priority – creating a barrier to making extra effort to become familiar with the TOCF. As mentioned in the earlier study by the participants, becoming familiar with the TOCF takes extra effort (Fox-Turnbull, 2017). For inexperienced technology teachers, an effort is needed to clarify any confusion they may have face in using the TOCF.

The two teachers were not very familiar with the terminology in the technology curriculum in NZC, as they mentioned in the interview and also evident from the classroom observations. The unfamiliarity with the terminology in the NZC could have led to the resistance that Jean showed to use the TOCF more frequently in the classroom or the resistance that Sarah-Jane initially showed towards the TOCF. Both teachers could then benefit from either a formal professional development in technology or a resource guide for the TOCF that could be developed to explain unfamiliar terminology. Developing a resource guide could also help teachers like Jean, who

may not have access to a researcher/ technology educator in the classroom for the initial support they need to start using the resource.

From the past study done on the TOCF and the experiences from this study, certain recommendations can be suggested about using the TOCF for teachers/teacher educators wanting to try out this resource.

1. Start with choosing only a few cards at a time. Choose one specific behaviour and 1-2 components.
2. Have these cards while starting to plan a technology unit.
3. Modify the language as you see fit for your students.
4. Read the cards multiple times until familiar.
5. Add more cards slowly and only when comfortable with the previous cards.

For teacher educators, an added recommendation could be to provide initial support for teachers not experienced in technology or inexperienced teachers who struggle to ask questions in classroom. Though the TOCF may seem like cards full of questions, due to the alignment with the technology curriculum, there may be unfamiliar terms for an inexperienced technology teacher.

Due to the paradigm of this research, it is not expected that the findings of this research are generalizable. However, the experiences stated here can be investigated in other technology classrooms and with other teachers to check if the conclusions hold true in those cases as well. This research can be extended in the future in other primary classrooms by studying which specific questions are challenging to adopt in the classroom and which are relatively straightforward.

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Contributing to reading comprehension through Science and Technology education

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Abstract

In this study, an educational development approach is investigated aiming at improving reading comprehension outcomes in primary education through inquiry and design-based Science & Technology teaching. The context is societal pressure to increase the likelihood that more students, later in their life, will aspire for careers in technology-intensive professions. However, schools are under more pressure to focus on core subjects, such as language. Integrated Science & Technology and Language education may overcome this problem. In this study, students from Years/Grades 3-6 (9- to 12-year-olds) received an experimental treatment, in which regular reading comprehension lessons were replaced by inquiry and design-based projects with a strong focus on oral language. Before and after, their performance on tests for reading comprehension was measured. No significant differences were found from performance in a control group, who received the regular reading comprehension lessons, but hardly any Science & Technology lessons. In the experimental group, teachers used the Skills Rubric Inquiry and Design and reported that students' skills for inquiry and design improved considerably. Substantial professional support in the form of weekly meetings in a professional learning community was necessary to achieve these goals. Initially, the teachers involved had little knowledge of Science & Technology and low self-efficacy with regard to teaching this subject, but teacher attitude towards teaching Science & Technology improved considerably during the project. It was concluded that integrating Science & Technology and language education is a complicated yet rewarding approach.

Key Words

primary education; STEM education; reading comprehension

Introduction and context

In many countries, shortages are reported with respect to technicians and engineers. For example, Ingrid Thijssen, the CEO of Alliander, a Dutch energy company, estimated that, to attain a national target for 2030 with respect to the transition of heating homes with natural gas towards using electricity, the country needs seven times as many technicians than currently enrol in vocational schools (ScienceGuide, 2019). And there are many other challenges and problems for which knowledge, skills and understanding of the material world is required. National and international agencies urge societies to put effort in this area, such as the OECD (2015), the European Commission (2015) and in the USA the National Academies of Sciences, Engineering, and Medicine (2020).

Dutch primary education does not differentiate science and inquiry from technology and design. Problems and questions that arise from interactions with the material world very often have a holistic character, with opportunities for both inquiry ('doing science') and design

(‘doing engineering and technology’). This is reflected in primary teaching and consequently, in this study, we will refer to the domain with ‘Science & Technology’.

Before enrolling in vocational schools or universities of technology, students receive their foundational education in primary schools. Here, an aspiration towards professions relying on Science & Technology may be cultivated, or not (cf. ASPIRES, 2014; Turner & Ireson, 2010). As Lucas, Hanson and Claxton (2104) state about the United Kingdom (p. 3): “Young children are little engineers. Yet the primary school system almost extinguishes any opportunities for them to flourish as engineers.” The Netherlands is not quite successful, too, as becomes clear from an analysis of the TIMSS results (Mullis, Martin, Foy, Hooper, 2016, cf. Meelissen et al. (2012) for a secondary analysis of TIMSS data for the Netherlands). Time spent on Science & Technology in primary schools (4%) is one of the lowest in OECD countries as is the percentage of students (13%) that experience the full circle of the phases of inquiry or design-based education. Often, Science & Technology is restricted to unreflected, often decontextualized, making or doing activities, without a proper problem analysis or additional reading. These facts were confirmed by a national survey carried out by the Dutch Inspectorate of Education (2017). Enrolment in degree programs in higher and vocational education that prepare for professions in science and technology in the Netherlands is 25%, and this is far below the OECD average of 40%. Of course, interventions in primary education can only have an indirect effect, but when attitudes and skills are not fostered at an early age, students will not be enabled to make career choices that suit their talents in the domain of Science & Technology. This, however, is not a longitudinal study investigating the ultimate effect of interventions in primary schools on career choices later in life. Rather, it supposes that a certain amount of time and good quality teaching are necessary conditions to attain this objective. In this respect, a survey among primary school principals in the Netherlands revealed that 93% are positive with regard to implementing design and inquiry-based Science & Technology teaching in their schools. Science & Technology education is supported for its importance with respect to participation in society and for its contribution to development of talents of the students. However, an impressive 98% of the principals is of the opinion that their teachers lack the pedagogical repertoire to do this (AVS, 2017).

An important reason for this is that the pressure on primary school teachers primarily comes from language and mathematics. Schools are monitored quite closely in this respect by the Dutch Inspectorate of Education. Schools that perform below average with respect to reading comprehension, taking into consideration the characteristics of their students such as their Social Economic Status, run the risk of interventions and even closing. This is not the case with poor performance in the area of Science & Technology. Partly, this is because there is no national assessment system that measures Science & Technology outcomes. The Netherlands do not have a national curriculum for Science & Technology, only a set of core objectives (Greven & Letschert, 2006). Although several of these are very much to the point (e.g., *‘The pupils learn to research materials and physical phenomena, including light, sound, electricity, power, magnetism, and temperature’*, and *‘The pupils learn to design, realise and evaluate solutions for technical problems’*), they are also quite generic and difficult to turn into a measurement system, certainly when each school is allowed to try to attain these objectives in its own way. The Dutch Inspectorate of Education tries to estimate Science & Technology teaching quality every six years with a twenty-item multiple choice test (Inspectorate of Education, 2017), but this test does not measure the skills for research or design mentioned in

the core objectives. And although the results of this test have been mediocre at best for the past twenty years, no action against schools has ever been taken. Consequently, under these circumstances, primary schools, which have to deal with many other pressing issues, can hardly be blamed not to invest in improving Science & Technology education just for Science & Technology's sake. But this situation also opens a backdoor: if Science & Technology education assists in achieving other objectives, for example difficult language skills like reading comprehension, then Science & Technology could make it to the curriculum. As Axell (2019, p. 89) states in the context of children's literature: "Fictional stories can also be connected to practical activities in technology and prevent technology education from becoming unreflected 'doing' activities." This sets the stage for the present study. Its objective is to explore the contribution that integrated Science & Technology and language education can make to both domains, under regular conditions. This study also explores if this kind of teaching can have a positive impact on teachers' own attitudes and self-confidence with respect to teaching Science & Technology.

Theoretical background

To be able to understand a written text, students first have to be able to decode the strings of symbols. Without knowledge of the letters and how letters build syllables, words and sentences, nothing goes. Experts agree that learning this requires structured, direct instruction and exercise. Typically developing children can acquire this skill when they are 6 or 7 years old (cf. McNamara 2010). Of course, there are important individual differences with regard to many aspects of mastering this skill, and some children are hampered by serious problems such as dyslexia. But that is not the topic of this study. We focus on another element that is important for reading comprehension, which is 'knowledge of the world'. Texts, in general, refer to things, events and situations in the world, and knowledge of these things, events and situations helps to understand the meaning of the text (Hirsch, 2003), as much as reading helps to develop a conceptual understanding of the world (RAND Reading Study Group, 2002). Research has shown that such concept-oriented reading instruction has a positive effect on strategy use and text comprehension (Guthrie, Van Meter, Hancock, Alao, Anderson & McCann, 1998).

In general, children acquire knowledge of the world through direct experience, often in combination with hearing the oral language that is uttered in the context. Oral language is an outcome of this interaction with the world and the need to communicate adequately with others (cf. Enfield, 2015; De Ruiter & Theakston, 2017). Conceptual or scientific understanding also is an outcome of this activity (Osborne, 2010). This opens a venue towards Science & Technology education. After all, Science & Technology education, certainly in the format of inquiry or design, is all about sensing, acting, exploring and experiencing the material world, with the implicit or explicit intention to understand this world and develop the knowledge and skills that are needed for direct survival, problem solving, meaning making and communicating with others. Consequently, for teachers in primary schools, exploring and communicating about the material world and using inquiry and design-based teaching formats could be a means to improve reading comprehension outcomes, through improved knowledge of the world and development of linguistic registers. It would allow schools to put Science & Technology on the timetable without the need to skip other subjects.

Indeed, there are many indications that Science & Technology learning and language learning benefit from each other. Guthrie, McRae and Lutz Klauda (2007) found positive outcomes for

students' science and reading achievement in an integrated approach. Vitale and Romance (2012) found that prior science knowledge helped to understand the meaning of texts. Reiser, Berland and Kenyan (2012) showed that oral discussions contribute to students' achievements by promoting sharing, critical analysis and collective reasoning about science practices. Lee, Quinn and Valdés (2013) see possibilities for common core standards for English language in relation to the USA's Next Generation Science Standards. Hand, Norton-Meier, Gunel and Akkus (2016) showed that students' argumentation skills profited from embedding language in primary science classrooms. Snow (2010) and Lin (2019) see development of domain specific academic language registers. However, positive effects have often been found through controlled interventions in which researchers were in the lead with respect to designing the educational materials and conducting the lessons (cf. Cervetti, Barber, Dorph, Pearson & Goldschmidt, 2012). Integrating Science & Technology and language teaching is a difficult pedagogic skill, as is inquiry or design-based teaching, and teachers need support to develop these skills (Gresnigt, Taconis, Van Keulen, Baartman & Gravemeijer, 2014). Moreover, most primary school teachers are not specialists with regard to Science & Technology: their content knowledge of Science & Technology disciplines is shallow, and many teachers regard themselves as 'non-tech'. Asma, Walma van der Molen and Van Aalderen-Smeets (2011) related teachers' apprehensive attitudes towards science and technology to students' interest. Teachers typically find it difficult to inspire their students towards Science & Technology (cf. Turner & Ireson, 2010; Potvin & Hasni, 2014; YoungWorks, 2016). This certainly is true of the average primary school teacher in the Netherlands. To develop teacher attitude towards Science & Technology and develop difficult teaching skills, substantive professional development is necessary. Promising approaches in this respect have teachers collaborate in communities of practice and give them the role of co-designers and co-researchers (Clarke & Hollingsworth, 2002; Stoll, 2015; Binkhorst, 2017).

Aim of this study

The aim of this study is to develop an approach that, from the point of view of primary schools, allows teachers to improve reading comprehension outcomes through inquiry and design-based teaching, and, from the point of view of modern, technological society, improves the likelihood that students aspire for higher education programs and careers in Science & Technology. We conjecture that substantive professional development is necessary for this.

We aim for a 'proof of concept study' in which we conjecture that the approach is valid if:

- a) The project is carried out in a setting that is representative of primary schools and teachers in the Netherlands, with the addition of professional development support.
- b) Reading comprehension skills of the students involved are better, or at least the same, as the skills of students from a control group that receives traditional reading comprehension lessons.
- c) Students involved have or develop a positive attitude for Science & Technology and improve their skills for inquiry and design.
- d) Participating teachers and schools feel empowered to teach integrated Science & Technology and Language lessons and continue doing this after the end of this research project.

Methods

In order to investigate our conjectures, we carried out a research project called 'Flywheels for reading comprehension', with financial support from the Dutch Research Council (NWO), grant 405-15-503. The experimental work was carried out in two primary schools in the city of Lelystad. Lelystad is a middle-sized city in the middle of the Netherlands. One of the experimental schools had students with average Social Economic Status (SES), one with SES well below average. Both schools are from the same School Board and share the principal and the remedial teacher. The project was carried out from 2014 (conception of the project) till 2017 (data analysis and final reporting). Data pertaining to students were gathered in 2015. The grant allowed the schools to reschedule the teaching workload, hire substitutes and enable several teachers to participate substantively in the project.

We formed a professional learning community (PLC) with the five classroom teachers who taught the upper Years/Grades (the 9- to 12-year-olds); the remedial teacher; and a researcher (the second author). All but one of the teachers were female. Their teaching experience ranged from three years to twenty. All but one initially described themselves as 'non-tech'. None had experience with inquiry or design-based teaching. The students came from four classes (one class had two teachers), compatible to UK Year/US Grade 3, 4, 5, and 6. One class was a mixed classroom 8- and 9-year-olds. We focused on the 9- to 12-year-olds and left out the data of the 8-year-olds.

The PLC met every week for three hours, first to develop a basic understanding of inquiry and design-based Science & Technology teaching, second to develop integrated lesson series on Science & Technology and reading comprehension, and third to discuss and reflect on the outcomes and on what had happened during the lessons. Occasionally, experts from the areas of Science & Technology or linguistics joined the PLC. Two lesson series, each of about 13 weekly lessons of approximately two hours, were designed and conducted by the teachers in their classes. The first lesson series was on how rivers flow and how dykes can be designed to contain the water, using a purpose-made sand-and-water table (Figure 1).



Figure 1 An experiment on how rivers flow

Water management is very important for the Netherlands and relies on many Science & Technology-related vocations. It is a meaningful context for students and easily links to their life world and daily experiences. The idea, information with respect to content knowledge, suggestions for lessons, and the sand-and-water table were provided by the research team on the basis of hydromorphological research carried out at the Faculty of Geosciences of Utrecht University (cf. Kleinhans et al. 2014; Van Wessel, Kleinhans, Van Keulen & Baar, 2014). The second lesson series was developed with the teachers in the lead and with less additional expert support. The theme of this series was 'Light and Vision'.

The point of the lessons series was that the students should explore material phenomena and solve technical problems. They were supposed to discuss their pre-knowledge, develop ideas, explanations, plans and reflect on findings in oral discourse with each other and with the teacher. The focus was very much on oral language. The teacher also stimulated that students should read about the topic. To achieve this, the school library in cooperation with the municipal library provided books that students could read (Figure 2).



Figure 2 Reading about light and vision

The researcher visited approximately ten percent of the lessons and, when appropriate, made video recordings for use in the PLC and for qualitative analysis. The Science & Technology lessons took the place of lessons normally devoted to reading comprehension, so no additional teaching time was involved. In order to estimate outcomes, we used several instruments. To be able to compare outcomes, two schools were involved as a control. These schools employed a standardized, commercially available approach to teach reading comprehension, which is quite regular in the Netherlands. The same material used to be used by the experimental schools.

To investigate reading comprehension, we used the school's longitudinal data base information on reading comprehension from the 'Cito LeerlingVolgSysteem Begrijpend Lezen'. This is a validated instrument with a five-point scale used widely in the Netherlands. We used this information to benchmark the individual students as 'weak' (score 1), 'average' (scores 2-4) or 'strong' (score 5) with respect to reading comprehension.

We used two tests on two different topics (called 'Fly, Eagle, Fly' and 'Discover the Fun of Day Hiking') from the international PIRLS study on reading comprehension (Mullis, Martin, Foy & Drucker, 2012) to test students' growing ability during the project. Half of the students took 'Eagle' as pre-test and 'Day Hiking' as post-test, for the other half the reverse design was used, in order to control for test differences. In order to estimate the effect of 'knowledge of the world' we constructed a new test with texts on the topics the students had investigated. We called this the Sand-Water-Light (SWL) test. We used exactly the same format as the official PIRLS tests, in order to be able to compare scores on the SWL-test to generic scores. The time between pre-test and post-test was six months.

To estimate the students' attitude towards Science & Technology we used the Pupils' Attitude Towards Technology (PATT) instrument in the Dutch language version of Ardies, De Maeyer, Gijbels and Van Keulen (2014). The PATT is a five-point Likert scale questionnaire containing items on aspirations, interest, consequences, difficulty, enjoyment and gender.

To estimate students' skills for inquiry and design teachers scored a sample of their students using the Skills Rubric Inquiry and Design (SRID). This is a high-inference instrument with the

scores based on accumulated classroom observations. The SRID was developed and validated in a pilot study in the Netherlands (Van Keulen & Slot, 2014) but has not been published in the English language. Therefore, the instrument is made available in Appendix 1. The SRID has two independent rubrics, one on inquiry and one on design. Both are divided into nineteen items and five scales, according to the stages and sub-skills for the inquiry or the design process (cf. Pedaste et al., 2015) and the underlying five psychological constructs, that is, skills for curiosity – skills for creativity – skills for executing plans – skills for critical thinking – skills for communication (Van Keulen, 2015). The SRID has four additional items on attitudes and other relevant skills (Enjoyment; Initiative; Social and Communicative Skills; Creativity and Originality). Each item has three performance categories (unsatisfactory; satisfactory; excellent) and each cell contains feedback suggestions a teacher might give to the student. In order to enable quantitative analyses, numerical scores can be given too, using a seven-point scale (unsatisfactory = 1-2; satisfactory = 3-5; excellent = 6-7).

To estimate teachers' attitude towards Science & Technology we used the Dimensions of Attitude towards Science (DAS) (Van Aalderen-Smeets & Walma van der Molen, 2013). The DAS is a five-point Likert scale questionnaire with three dimensions: 'Cognitive Beliefs' (with the factors 'Perceived Relevance', 'Perceived Difficulty' and 'Gender Beliefs'); 'Affective States' (with the factors 'Enjoyment' and 'Anxiety'); and 'Perceived Control' (with 'Self-efficacy' and 'Context Dependency'). The DAS has two sets of items, in order to measure both professional attitude (pertaining to classroom teaching) and personal attitude (pertaining to daily life). It also has questions on predispositions to act in personal and professional life (Behaviour Disposition Personal and Professional).

In order to estimate the effectiveness of the whole approach teachers kept a journal. The PLC-discussions were logged. The researcher made field notes when observing lessons. These sources of data were analysed qualitatively, following the principles of Educational Design Research (McKenney & Reeves, 2012) with open coding and inductive analysis (Saldaña, 2015), and using De Groot's (1974) categories for analysing learning reports. De Groot urges to pay attention to learning experiences pertaining to rules, like: "I have learned that it is important to start with taking stock of what the children already know about the topic", and exceptions to rules, like: "Most children are eager to say what they think is happening, but some children need encouragement". De Groot also emphasizes the importance of learning experiences that express surprise about the world or oneself, like: "I hadn't realized that water flows faster in the outside bend of a river", and: "I was surprised that there could be so much content-oriented talk during experiments".

A summary of the instruments and the participants is presented in Table 1. As is visible in the table, numbers on pre- and post-tests differ slightly, mainly due to illness of students and to pregnancy, in the case of the teachers.

Table 1 Summary of instruments and number of participants

	Pre-tests				Post-tests			
	PIRLS	PATT	SRID	DAS	PIRLS + SWL	PATT	SRID	DAS
Students experimental schools	71	73	8		69	67	8	
Students control schools	60	68	-		55	-	-	
Teachers experimental schools				5				4
Teachers control schools				8				-

Results and conclusions

Students' reading comprehension

The outcomes with respect to reading comprehension test scores are expressed in Table 2. We first compared the mean standardized scores on the PIRLS pre-test of the experimental group with the control group (Table 2, A).

Table 2 Comparison of reading comprehension scores

	A: Pre-test PIRLS			B: Post-test PIRLS			C: SWL-test		
	N	Mean	Standard deviation	N	Mean	Standard deviation	N	Mean	Standard deviation
Experimental group	71	.88	.328	67	.93	.323	67	.55	.167
Control group	60	.98	.283	66	1.05	.294	66	.59	.137
Total	131	.92	.312	133	.99	.314	133	.57	.154
	$p=.048$ (significant for $p<.05$)			$p=.020$ (significant for $p<.05$)			$p=.131$ (not significant for $p<.05$)		

The schools draw their students from different districts, with different characteristics such as SES. This is reflected in the scores: the control group scores significantly better. We then compared the scores on the PIRLS post-test. Again, the control group scored significantly better (Table 2, B). Next, we compared the growth in reading comprehension as the difference between pre- and post-test between the experimental group and the control group. This difference proved to be not significant, implying that the experimental group had improved as much as the control group, apparently on the basis of oral discussions and reading out of interest.

We also compared the scores on the Sand-Water-Light (SWL) test. The mean scores on this test are expressed as percentage of correct answers, since this is a unique test that is not standardized, as are the PIRLS tests. Here, the difference between the experimental group and the control group was not statistically significant (Table 3, C). Given the significant difference in reading comprehension competence on generic texts (PIRLS) between the two groups, we take

this outcome as an indication that 'knowledge of the world' does indeed contribute to reading comprehension, and that Science & Technology lessons with a focus on oral language are a means to develop reading comprehension skills. We also tried to make comparisons within the experimental group between strong, average and weak readers to find out which sub-group benefited most from the experimental condition, but due to small numbers of both strong and weak readers, this analysis failed to pinpoint any significant effects.

Students' attitude for Science & Technology

The scores on students' attitude for Science & Technology were measured with the PATT. The attitude of the experimental group is presented in Table 3. Table 4 presents the comparison with the control group.

Table 3 Attitude for Science & Technology for the experimental group

	Pre-test (n=61)		Post-test (n=61)		Comparison	
	Median	Range	Median	Range	Z	p
Aspiration	2,67	3,00	3,00	3,50	1,680	0,093
Interest	3,00	2,50	3,00	2,50	0,994	0,320
Consequences	2,00	3,00	2,33	3,00	0,799	0,424
Difficulty	3,00	3,50	3,00	4,00	1,354	0,176
Gender	4,00	4,00	3,67	4,00	0,684	0,494
Enjoyment	3,50	2,75	3,33	2,25	-0,930	0,352

Table 4 Comparison of attitude scores between experimental and control group

	Experimental group (n=61)		Control group (n=68)		Comparison		
	Median	Range	Median	Range	U	z	p
Aspiration	3,00	3,50	2,83	3,33	2007,500	-0,156	0, 876
Interest	3,00	2,50	2,88	2,75	1887,000	-0,738	0, 461
Consequences	2,33	3,00	2,00	3,00	1397,500	-3,120	0, 002*
Difficulty	3,00	4,00	2,75	4,00	1666,000	-1,795	0, 073
Gender	3,67	4,00	3,00	4,00	1499,000	-2,598	0, 009*
Enjoyment	3,33	2,25	3,25	3,00	1926,500	-0,548	0, 583

*significant $p < .05$

As can be seen in these tables, the students are quite positive with respect to Science & Technology. They think it is important and enjoy the lessons. They are neutral with respect to difficulty, interest and their aspirations. They disagree that Science & Technology is more appropriate for boys than for girls. These positive attitudes did not change much during the intervention. Also, students in the control group did not differ much in attitude. Clearly, it is not because of the attitude of these students that Science & Technology plays a minor role in their schools.

Students' skills for inquiry and design

In both the experimental and the control schools, Science & Technology education was almost absent on the timetable. Typical activities ranged from collecting chestnuts in autumn to watching a video on robotics. None of the teachers involved was acquainted with inquiry or

design-based education. It had been established that teachers with experience in inquiry and design-based teaching needs four to five minutes to score one student with Skills Rubric Inquiry and Design (SRID). Teachers that are not only inexperienced with the instrument but also unfamiliar with the behaviour of students in inquiry or design-based education, need a lot more time and their observations may also not be very reliable. We decided not to use the SRID in the control group, and to limit the use of this instrument to a small sample of students in the experimental group, in order not to overwhelm the teachers. Three of the teachers each scored three of their students, who were selected on the expectation that they would respectively be weak, average and strong in inquiry and design. One of the students dropped out due to illness, so the eventual analysis is based on 8 students, who were scored in the beginning of the project and at the end. Teachers also did not score all (2 times 19) items but limited themselves to the five categories pertaining to the stages of inquiry and design, and the attitudes. The scores are presented in Table 5.

Table 5 Scores on the Skills Rubric Inquiry and Design (1- to 7-point Likert scale)

	Pre-test (n=8)		Post-test (n=8)		Comparison	
	Median	Range	Median	Range	Z	p
D: Design	3,70	3,60	4,60	3,40	2,038	0,042*
D1: Problem recognition	4,00	4,00	5,00	3,00	2,070	0,038*
D2: Designing a solution	3,00	4,00	4,50	5,00	1,947	0,052
D3: Realising the design	4,00	2,00	4,50	3,00	1,134	0,257
D4: Testing and improving	3,50	4,00	4,50	3,00	1,200	0,230
D5: Presenting	3,00	4,00	4,50	4,00	2,266	0,023*
I: Inquiry	3,70	3,80	4,10	3,40	1,680	0,093
I1: Curiosity and hypothesizing	5,00	4,00	5,00	4,00	1,265	0,206
I2: Gathering data to answer the question	3,50	4,00	4,00	3,00	1,725	0,084
I3: Analysing data	3,50	5,00	3,50	5,00	1,211	0,226
I4: Drawing conclusions and critical reflection	3,00	4,00	4,00	4,00	1,852	0,064
I5: Presenting	3,00	4,00	4,00	4,00	1,552	0,121
A: Attitudes and other skills	4,00	4,00	4,75	3,50	0,594	0,553
A1: Enjoyment, interest and motivation	5,00	3,00	6,00	3,00	0,638	0,524
A2: Initiative and executive functioning	3,50	5,00	4,50	4,00	0,954	0,340
A3: Communicative and social attitude	4,00	6,00	4,50	5,00	0,604	0,546
A4: Creativity and originality	5,00	3,00	4,00	3,00	-0,816	0,414

*significant $p < .05$

Given the complications with scoring these skills and the small number of students, we cannot really draw reliable conclusions with respect to the development of skills for inquiry and design. However, as can be seen in the table, the teachers were of the opinion that all students improved greatly. This they also expressed in the professional learning community. They were surprised how much all students enjoyed the lessons, even those who did not regularly show involvement in scholarly work. Also, the teachers evaluated the instrument positively. It helped

them, they said, to understand better what inquiry and design-based teaching is about, and how to observe their students in new ways in the future.

Teachers' attitude towards Science & Technology

The scores for teachers' attitude towards Science & Technology, as measured with the DAS, are presented in Tables 6. Comparisons with the control group are made in Table 7.

Table 6: Development of attitude towards Science & Technology in the experimental group (DAS)

	Pre-test (n=5)		Post-test (n=4)		comparison	
	Median	Range	Median	Range	Z-score	p
Cognitive belief personal						
Perceived relevance	3,50	0,75	3,375	1,00	0,378	0,705
Perceived difficulty	4,50	2,75	4,00	3,00	-0,707	0,480
Gender Beliefs	3,00	2,50	2,50	3,00	-0,365	0,715
Cognitive belief professional						
Perceived relevance	4,00	1,00	4,10	0,80	0,000	1,000
Perceived difficulty	4,00	1,34	3,835	1,67	-1,089	0,276
Gender Beliefs	2,75	2,75	2,875	0,75	-0,365	0,715
Affective states personal						
Enjoyment	4,00	1,00	3,875	2,00	0,000	1,000
Anxiety	3,50	2,75	3,00	3,00	0,816	0,414
Affective states professional						
Enjoyment	3,25	0,75	4,00	2,50	0,447	0,655
Anxiety	3,25	3,25	2,00	3,00	-1,604	0,109
Perceived Control personal						
Self-efficacy	2,75	0,75	2,875	1,50	0,378	0,705
Context Dependency	3,00	1,33	3,165	2,66	-0,378	0,705
Perceived Control professional						
Self-efficacy	3,00	2,00	3,10	1,80	1,461	0,144
Context Dependency	4,00	2,33	3,50	2,67	-1,633	0,102
Behavioural disposition personal	2,17	1,50	2,25	1,34	-1,069	0,285
Behavioural disposition professional	1,71	0,43	3,07	1,14	1,841	0,066

Table 7: Comparison of attitude towards Science & Technology between experimental and control group

	Experimental group (post-test) (n=4)		Control group (n=8)		Comparison		
	Median	Range	Median	Range	U	Z-score	p
Cognitive belief personal							
Perceived relevance	3,375	1,00	3,00	0,75	6,50	-1,729	0,084
Perceived difficulty	4,00	3,00	3,25	1,75	10,50	-1,398	0,162
Gender Beliefs	2,50	3,00	3,125	3,00	14,50	-0,257	0,797
Cognitive belief professional							
Perceived relevance	4,10	0,80	3,20	1,60	3,00	-2,235	0,025*
Perceived difficulty	3,835	1,67	3,165	1,67	5,00	-1,892	0,059
Gender Beliefs	2,875	0,75	2,50	2,75	8,00	-1,378	0,168
Affective states personal							
Enjoyment	3,875	2,00	3,75	2,25	12,00	-0,695	0,487
Anxiety	3,00	3,00	2,50	2,50	13,50	-0,426	0,670
Affective states professional							
Enjoyment	4,00	2,50	3,00	2,50	7,50	-1,462	0,144
Anxiety	2,00	3,00	2,375	2,75	14,50	-0,260	0,795
Perceived Control personal							
Self-efficacy	2,875	1,50	2,50	2,50	15,00	-0,174	0,862
Context Dependency	3,165	2,66	2,67	1,33	10,00	-1,041	0,298
Perceived Control professional							
Self-efficacy	3,10	1,80	3,10	2,00	14,50	-0,256	0,798
Context Dependency	3,50	2,67	3,50	2,00	14,50	-0,261	0,794
Behavioural disposition personal							
Behavioural disposition personal	2,25	1,34	2,00	1,50	11,00	-0,868	0,386
Behavioural disposition professional							
Behavioural disposition professional	3,07	1,14	1,71	1,00	0,00	-2,737	0,006*

*significant $p < .05$

The DAS is an instrument that is validated for large numbers, but this study focuses on a small number of teachers, implying that any differences have to be huge in order to become statistically significant. So, we concentrated on the absolute findings and add qualitative

information from the reflective discussions in the professional learning community (PLC) to the interpretation.

Clearly, the experimental teachers showed signs of apprehension in the pre-test. They knew they were going to do something new, which they perceived as important and good to do but also as difficult. Both Professional Perceived Relevance and Professional Difficulty come out high. An effect of the intervention is clearly visible in the data: Professional Behaviour Disposition grew from 1.71 to 3.07, whereas Professional Anxiety was reduced from 3.25 to 2.00. Teachers also feel less dependent upon help from the context. This interpretation was confirmed by the teachers in the PLC. They expressed that they were more and more looking forward to the lessons, and that teaching became less difficult and more enjoyable. One teacher, for example, expressed that she had learned that it is not necessary to know all about Science & Technology, and that not knowing things can even be beneficial because it makes the investigation more interesting to the students and makes it easier to adopt a coaching role. The teachers appreciated the discussions and exchange of ideas and experiences in the PLC and stated that this helped them to overcome anxieties towards Science & Technology teaching. We conclude that professional development, co-designing and reflective discourse in a PLC contributed to developing a positive professional attitude towards Science & Technology teaching.

Qualitative findings with respect to integrating Science & Technology and language

Initially, the teachers had no intention to integrate Science & Technology and language in their lessons. It was the principal of the school who convinced them to take part in the experiment and try out something new. Schools in the Netherlands typically use different textbooks for every individual subject; integration runs against this practice. Although the teachers did not deny that oral discussions about material phenomena such as water management could help contribute to building a domain specific and academic vocabulary and to other language skills, they could not easily relate this to the highly structured learning progressions prescribed by the textbooks on reading comprehension. They feared that leaving out the normal reading comprehension lessons would result in weak test scores and thus put their professional credibility into question. They were relieved that the post-test scores were as good as they should be, but during the project they also became convinced that the integrated approach had other merits. They had feared that they would lose control, and indeed this happened once in a while, but they also noticed that students assumed control, were far more involved and 'time on task' was higher than in a typical direct instruction reading comprehension lesson. They noticed the power of material phenomena, such as a dyke that collapses under the pressure of water, to draw attention, provoke curiosity and sparkle off discourse and a hunger for explanations. Students who were normally not motivated to read now became more interested readers on the topics of the lessons. Importantly, the teachers' skills for scaffolding group discussions improved with experience. Teachers became better in asking questions, involving all students, summarizing, and drawing conclusions. One teacher stated that she started using this scaffolding and discourse repertoire in other lessons as well. Also, teachers' conceptions of reading comprehension developed. Whereas at the start of the project they did not relate reading comprehension to knowledge of the world and oral discourse, at the end they were

able to explain to colleagues how domain specific knowledge acquired through experience and discourse can have an impact on vocabulary, reasoning styles, and the understanding of texts.

Implementation and proof of concept

We conjectured that this approach would proof the concept of integrated Science & Technology and Language Education if (1) participating teachers and schools felt empowered to teach integrated Science & Technology and Language lessons and continue doing this after the end of this research project; if (2) reading comprehension skills of the students involved were better, or at least the same, as the skills of students from a control group that receives traditional reading comprehension lessons; and if (3) the students involved had or had developed a positive attitude for Science & Technology and improved skills for inquiry and design. We conclude that these criteria were met. The approach became indeed implemented in the normal routine of one of the schools, with new incoming teachers learning through co-teaching from their peers. Although the Netherlands currently has teacher shortages and a huge turnover, and all participants except one have left the school at the moment of writing this article (2019), the integrated Science & Technology and reading comprehension module still is firmly in place, and test results for reading comprehension have started to increase. The control schools, and most other schools in the vicinity, however, although they were informed and supplied with all lesson plans and other materials, remained apprehensive towards integrating Science & Technology and reading comprehension. This is in line with our last conjecture, namely (4) that substantial professional development, such as provided in a Professional Learning Community, is necessary. This study thus affirms that it is possible to integrate inquiry and design-based Science & Technology teaching with reading comprehension with good results for both subjects, and in a setting that is representative of primary schools in the Netherlands.

Discussion

This study confirms that Science & Technology education can contribute to the development of linguistic skills, such as reading comprehension. It adds to the theoretical framework by exploring issues of implementation in regular practice. The design of this study allowed more ownership to teachers than in many other experimental designs, leading to lasting implementation: the teachers themselves co-designed the lessons, carried out these lessons, reflected on the experiences and became conscious of their expanded repertoire. They found ways to implement the approach in their school's curriculum, being able to take into account the idiosyncrasies that characterize each and any individual school. Although the teachers were not selected randomly, they were not biased in favour of Science & Technology. On the contrary, their knowledge and self-efficacy was weak at the outset but developed during and on behalf of this project.

To achieve this, a substantive in-service professional development program was necessary. This requirement had consequences for the possibilities to quantify outcomes and draw conclusions that are wider than pertaining to this small population of teachers and students. A power analysis on the basis of the magnitude of the effects that were found suggests that at least 300 students would have been necessary to generate differences that are of statistical significance, and which would also have allowed us to discriminate between weak, average and strong readers. However, this would have meant a fivefold increase of the cost of the project, since it

is not the development and conduct of the lessons that takes so much time, but the many meetings in the professional learning community. Although all lesson plans and reports were made available to the control schools and all other schools in the district, none of these started with integrated language and Science & Technology lessons on their own. Apparently, development of positive attitude towards Science & Technology, especially with respect to professional perceived control (self-efficacy and context-independency), is a prerequisite. The Netherlands are quite unique compared to most other countries for its absence of a prescribed curriculum and national testing for Science & Technology, in combination with core objectives that are not very specific. This allows schools professional freedom and autonomy and could, in principle, lead to excellent teaching quality and to good learning outcomes. However, this is not the case. Without a curriculum, without clear standards, without inspection, and with many other challenges competing for time and effort, this system is not working for Science & Technology. The Netherlands has approximately 6,000 primary schools and 125,000 teachers, and many do an excellent job, but the countrywide results with respect to Science & Technology are disappointing.

Inquiry and design-based Science & Technology education, as well as integrative teaching, require advanced pedagogic skills. The foundations for this are laid in the teaching certificate programs, which in the Netherlands is at the bachelor's level. Apparently, this is not enough. Alternative approaches, leading to higher professional qualifications can be found in countries that serve their primary schools with degree programs at the master's level or stimulate teachers to specialize in a subject, e.g., the arts, mathematics, or Science & Technology. Does Science & Technology education require a master's level and/or subject specific qualification to be successful? Which country is doing really well on Science & Technology, and what are the investments and trade-offs?

There is, however, another side to this coin. When reading comprehension skills can be advanced through Science & Technology, and both students and teachers are satisfied with this, then teaching Science & Technology education is a strategy to meet educational challenges from other domains. If this approach works for reading comprehension, it may work for citizenship, for entrepreneurial thinking, for the arts, or for special needs education. From this point of view, learning about Science & Technology is a bonus for schools who invest in integration.

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Appendix 1 Skills Rubric Inquiry and Design

Skills Rubric Inquiry			
	<i>Unsatisfactory (1-2)</i>	<i>Satisfactory (3-5)</i>	<i>Excellent (6-7)</i>
Curiosity / exploring the problem			
I1.1. Asking questions	Doesn't ask questions. Appears not to be interested.	Appears to be curious. Asks questions that relate to observations ('What is that?'; 'Why is the sky blue?')	Asks many questions. Shows an eagerness for knowledge. Is interested in relationships between observations. Asks questions based on reasoning.
I1.2 Using previous knowledge	No signs that existing knowledge, skills or experiences are used.	Draws explicitly on previous knowledge and experiences.	Has knowledge on many subjects and shows this. Easily relates new experiences to previous knowledge.
I1.3 Problem exploration	Doesn't explore the problem. Is passive. Is not committed to the inquiry task.	Explores intuitively. Looks; feels; tries; uses sensorimotor experiences. Seeks on the internet or uses other sources.	Explores systematically. Can provide clear reasons for exploring this way. Is not afraid to try new ways. Has specific expectations. Poses focused questions. Finds good sources of information.
I1.4 Confining the problem	Doesn't bother whether the problem is too big or complicated to investigate.	Transform the initial problem into a research question. Is explicit about the focus of the inquiry.	Knows how to confine problems. Is explicit about what is most and what is less important to investigate. Provides reasons for choices.
I1.5 Expectations	Has no specific expectations. Doesn't take into account possible constraints.	Is explicit about what to expect as an outcome of the inquiry.	Is explicit about what to expect. Bases expectations on previous knowledge and logical thinking. Takes constraints and circumstances into account.
Creativity / designing activities to answer the research question			

12.1 Making a plan	Doesn't know what to do to answer the question Doesn't make a plan.	Comes up with ideas how to answer the question. Designs experiments. Has a plan.	Designs an experimental plan that covers all questions. Takes issues of validity and reliability into account.
12.2 Conducting experiments	Doesn't stick to the plan when investigating.	Conducts the experiments and other ways to gather data according to the plan.	Carries out the plan carefully and compares outcomes to expectations. Repairs mistakes.
12.3 Observing	Doesn't pay attention to what is observable.	Is attentive. Concentrates on what is to be observed.	Observes systematically. Is not easily distracted. Has an eye for the unexpected. Sees relationships between observations.
Executive functions /Gathering data and transforming observations into results			
13.1 Capturing data	Hardly takes notes. Cannot reconstruct observations. Commits errors when capturing data. Needs help.	Captures data according to plan. Doesn't make mistakes. Can recapitulate the observations.	Captures data systematically and unequivocally. Takes notice of phenomena that were unexpected. Recapitulates the observations clearly and completely.
13.2 Data handling	Doesn't structure the data. Doesn't elaborate on raw data.	Structures the data. Provides tables, charts, drawings or other elaborations.	Structures and elaborates on the data correctly and adequately. Notices outliers and contradictory evidence.
13.3 Focusing on the essentials	Is clueless with respect to what is important.	Knows what is essential and what are the minor points	Clearly differentiate major and minor issues. Uses the research question to prioritize.
Critical thinking / Concluding and discussing			
14.1 Drawing conclusions	Cannot see if the research question has been answered.	Draws conclusions on the basis of the results. Compares	Presents results and conclusions as answers to the

	Focuses on what has been done and not on outcomes.	outcomes with expectations.	research questions. Draws inferences that are credible. Builds on existing theory.
14.2 Critical reflection	Doesn't use criteria to reflect on the outcomes and conclusions.	Discusses whether the conclusions are credible. Leaves room for alternative explanations.	Uses criteria such as theoretical grounding, (statistical) significance, limitations and practical relevance to evaluate conclusions. Looks actively for alternative explanations. Makes suggestions for further research.
Communicating			
15.1 Preparing a presentation	Is unable to prepare a presentation that covers the research design.	Is able to prepare an oral or written presentation that covers the problem, the research design, the results and the conclusions.	Is able to prepare a presentation the whole inquiry process in various oral and written formats. Adequately uses visuals and other media. Clearly presents hypotheses, research questions and conclusions.
15.2 Giving a presenting	Presents in a way that doesn't adequately communicate the investigation.	Presents the initial problem, the research design and the most important outcomes adequately.	Covers the whole research. Provokes the curiosity and interest of the audience or readers. Handles questions, critique and feedback well.
D5.3 Implications	Doesn't focus on implications and further research.	Pays attention to potential consequences and actions that logically follow from the study.	Pays attention to how the study contributes to practice and/or theory.

Skills Rubric Design			
	<i>Unsatisfactory (1-2)</i>	<i>Satisfactory (3-5)</i>	<i>Excellent (6-7)</i>
Curiosity / Recognizing and exploring a problem			
D1.1. Recognizing problems	Doesn't recognize a problem. Accepts things as they are. Perceptions have no consequences. "It is broken". No non-verbal signs of longing or interest.	Is attentive. Wants to know how things are made. States a desire or a problem on the basis of an observation or annoyance. "Couldn't that be better?"	Has an eye for things that can be improved. Is able to indicate why something is a problem that should be solved.
D1.2 Using previous knowledge	No signs that existing knowledge, skills or experiences are used.	Recognizes relations between a problem and previous experiences: "I have seen this before". Explicitly mentions relevant previous knowledge ("Trusses can make a bridge stronger").	Has knowledge on many subjects and shows this. Knows many existing solutions to technological problems.
D1.3 Problem exploration	Doesn't explore the problem. Is passive. Is not committed to the design task.	Explores intuitively. Looks; feels; uses sensorimotor experiences. Seeks on the internet or other sources. Tries to explain why the problem should be explored in this way.	Explores systematically. Can provide clear reasons for exploring this way. Is not afraid to try new ways. Has specific expectations. Poses focused questions. Finds good sources of information.
D1.4 Confining the problem	Doesn't bother whether the problem is too big or complicated for solving. Is guided by what is at hand.	Focuses on what is possible to achieve with one's capabilities.	Knows how to confine the problem. Is explicit about what is most and what is less important. Provides reasons for choices.
D1.5 Specifications	Doesn't take the requirement of a solution into account. Thinks about solutions	Can justify the solution to the problem with an appeal to specifications	Can take the user's point of view. Starts with formulating specifications. Takes constraints and

	without constraints or specifications.		circumstances into account.
Creativity / Designing solutions			
D2.1 Proposing a solution	Doesn't propose any ideas. Is not able to suggest a solution.	Proposes solutions. Is mainly inspired by existing solutions. Needs confirmation to continue on a track.	Uses the specifications to design solutions. Reasons in terms of function-form or means-goal. Proposes original and creative ideas.
D2.2 Choosing a solution	Provides no, or no good, reasons. Wants to do what is fun.	Provides at least one good reason for choosing a proposal.	Critically discusses the choice from the point of view of the specifications. Is explicit about disadvantages and possible trade-offs.
D2.3 Making a plan	Doesn't make a plan. Or, plans are sloppy, incomplete or incomprehensible to others	Makes an adequate plan that is comprehensible to other	Makes a detailed plan. Addresses all activities. Schedules. Is explicit about which materials, tools, et cetera to be used. Makes drawings.
Executive functions / Carries out the design			
D3.1 Use of materials and tools	Is unable to use the necessary materials or tools. Needs help.	Is able to use the necessary materials and tools.	Is skilful with materials and tools. Decides which materials or tools are most adequate. Provides reasons for choices.
D3.2 Making of the design	Is unable to make the artifact, even with help.	Is able to make the artifact, perhaps with some help. Sticks to the plan.	Is independent and careful. Has a repertoire of techniques. Is skilful. Solves problems.
Critical thinking / Testing and improving the design			
D4.1 Testing the design	Doesn't test the design systematically.	Checks whether the design meets the overall specifications. Judges in terms of 'yes' or 'no'.	Systematically checks whether the design meets all specifications. Is critical and nuanced. Repeats tests. Discovers the most

			important flaws and mistakes.
D4.2 Trouble shooting	Ignores or downplays problems. Doesn't look for causes or solutions. Doesn't propose suggestions that would improve the design.	Is aware of problems or mistakes. Proposes suggestions for improvement.	Understands and explains problems. Searches systematically for solutions. Uses previous knowledge. Has creative ideas for improvement.
D4.3 Redesign	Doesn't succeed to carry through improvements. Is easily discouraged.	Carries through improvements. Is eventually able to meet most specifications.	Solves all problems satisfactorily. Doesn't tinker. Keeps the integrity of the design.
Communicating			
D5.1 Giving a presentation	Is unable to give a presentation that outlines the problem, the proposed solution and an evaluation whether the design meets the specifications.	Is able to give a presentation that outlines the problem, the proposed solution and an evaluation whether the design meets the specifications.	Is able to clearly present the whole design process in word and writing. Adequately uses drawings, figures, graphs, and other data.
D5.2 Justification	Doesn't indicate whether the design meets the specifications or solves the problem. Just describes what is done or made.	Justifies the design in terms of solving the problem.	Is able to indicate the quality of the design and its components. Uses function-form and other argumentations. Indicates the possibilities for use and improvement.
D5.3 Sharing	Doesn't speak about the design. Is not involved.	Speaks when asked and spontaneously about the design. Mentions striking experiences.	Speaks spontaneously, with detail and with involvement about the design, the process, the product and the possibilities for use. Is fully committed.

Rubric Attitudes and generic skills	
A1 Enjoyment, interest and motivation	Students who enjoy inquiry and design are enthusiastic, show involvement, take initiative and talk spontaneously about what they are doing and thinking. For example, they engage in activities to find more information about the topic. They ask questions to themselves and to others.
A2 Initiative and executive functioning	Students who take initiative look for situations and possibilities to expand and apply their knowledge and skills. Students with good self-regulation skills manage to get along through the design cycle without much teacher support and intervention. They can plan, stick to the plan or change the plan when necessary. They feel responsible, focus on the
A3 Communicative and social attitudes	To be able to cooperate is not just a skill but also an attitude that can be enhanced through inquiry and design assignments. A student with a communicative and social attitude is interested in the contribution of others, listens attentively, is respectful, elaborates on what others do and say, pays attention to the process of decision making, shares ideas, employs the
A4 Creativity and innovation	Creative students have, more than others, the ability to come up with new ideas, explanations and solutions. They see relations and combinations that are not yet visible to others. They can think 'out of the box'. They are more able than others to learn from examples and to utilize pre-knowledge and

Young Children's Representational Structures of Robots' Behaviors

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Abstract

Despite the fact that the sophisticated technologies are a substantial component of children's everyday environment, of the space within which they act, play and learn - the world of complex technological systems (their characteristics, and the knowledge and skills involved in operating, designing and programming them) is almost ignored in the preschool and elementary school curriculum. The study reported in this paper is part of a research plan embedded in the implementation of a comprehensive curriculum aiming to support the development of technological thinking in kindergartens, including knowledge and skills in areas such as design, the artifacts in our material culture, smart artifacts and robotic systems, or programming. This particular study aimed to address young children's (aged 5-8) perception of the adaptive behavior of a robot and the representational structures (or functioning schemes) they adopt to think about how its behaviors are generated and controlled. When children think about the robot's behavior, they may adopt different perspectives that translate into different representational structures, (e.g., one-time episodic representation; a script that can become a reusable routine; a universal representation such as a rule of behavior). The findings evidence the ability of young children engaged in programming to think in terms of abstract rules and to use these for programming and designing a robot's behavior.

Keywords

Robotics, representational structures, kindergarten, programming

Young Children's Representation of Robots' Behaviors

A. (preschooler) says immediately after finishing to program the robot:

...I did it nicely. I had an idea. It wasn't easy. First, I got thinking, then I saw that it didn't help, then I knew that it would do it all the time and then it would get out of the maze. It's easy, I thought with the help of the robot suggesting an idea, and then I knew...

L. (first grader) adds while looking at the robot traveling on a black strip:

... How does it know how to turn around on this thing?? You (meaning the researcher) made it happen with a computer. But how does he know from the computer? The man is so small, so how can he see from the computer? The man inside this car (the robot). A little man, I can't see it. The man is smaller than a germ. He simply goes and sees what is written on the computer and moves it (the robot) ...

These are just two examples (out of many) of kindergarten and first grade children reflections on a robot's behavior. A. describes the programming and debugging process, while L. tries to understand what is happening – why the robot behaves in the way it behaves. Both child's descriptions include anthropomorphic references to the robot. However, L. has difficulty at understanding that the autonomous behavior of the robot results from running code written by a programmer.

Young children are exposed to controlled technological systems from an early age – supermarket doors, programmable toys, smartphones, sophisticated appliances, or control systems embedded in many familiar devices in the environment. Young children play, try out, and learn to operate these systems as part of their daily lives. Given that sophisticated technologies are such a substantial component of children's everyday environment, of the space within which they act, play and learn - why the world of complex technological systems (their characteristics, and the knowledge and skills involved in operating, designing and programming them) is almost ignored in the preschool and elementary school curriculum?

With this overarching question in mind, we have developed, studied and implemented for more than a decade a comprehensive curricular intervention for kindergartens in Israel focusing on technological thinking skills and knowledge. Among the range of curricular strands and batteries of tasks implemented and examined, there are issues related to children's understanding of the structure and functioning of smart artifacts - the context of the study reported in this paper. The study addresses a specific aspect: young children's (aged 5-8) perception of the adaptive behavior of a robot and the representational-structures (or functioning schemes) they adopt to think about how its behaviors are generated and controlled.

A basic research assumption for the study was that when the children program the robot's behavior, they use different representational structures (e.g., one-time episodic representation; a script that can become a reusable routine; a universal and a-temporal representation such as a rule of behavior). The actual implementation of each representation obviously embeds differences in understanding the robot's functioning as well as in planning and programming strategies generating its behavior.

The main question examined in the study was: What are the representational-structures of control (i.e., episode, script, rule) used by young children (5-8 years) to represent a robot's adaptive behavior.

Background

Children's activities in a robotic environment imply acknowledging different types of behaviors of the system: from sporadic or one-time events (episodes), through reusable organized behavioral patterns (script), to time-independent behavioral patterns (e.g., rules) connecting between environmental conditions and robot's actions. A **script** is a generalized, temporally and spatially organized sequence of events about some common routine with a goal. Using a **script** is characteristic of preschoolers' thinking – for example, they create scripts when engaged in playing sociodramatic games (Mioduser, Levi & Talis, 2009) or in describing temporal events (Flavell,

Miller, & Miller, 1993). Young children have difficulty in formulating the necessary proofs to examine a hypothesis, therefore have problems in drawing conclusions. Despite this, children can “draw” conclusions from actual observed data, obtained through active participation in its generation, e.g., a programming-and-program-running task.

Concerning **rules**, studies focusing on children’s understanding of cause/effect relationships showed that children can distinguish a behavioral pattern in a robot’s functioning and use these for predicting and planning its behavior (Siegler, 1986; Sobel, Tenenbaum, and Gopnik, 2004). While coping with a programming task, children will first look at the robot’s functioning and describe it step by step in time, thus generating a script. However, the continuous use of scripts along different tasks leads to the perception of patterns and to the formulation of rules independent of time and expressing generally relationships between inputs and outputs (Mioduser, Levi & Talis, 2009). Using a rule is obviously different from using an episode or a script. Siegler (1986) describes four processes that occur when a new rule is learned:

- The ability to refer to and explain key variables.
- The ability to formulate a general rule.
- The ability to generalize to other contexts.
- Preserving the rule even after the intervention is over.

Research has shown that children perceive initially a robot’s behavior as a one-time event – an episode. They focus on the robot’s behavior while ignoring its interaction with the environment. Such focus on the robot’s observable behavior is the basis of Papert’s claim (1993) that the learner identifies herself with the behaving artifact and focuses on interpreting its behavior as a finite sequence of behavioral units. The study by Mioduser, Levi & Talis (2009) shows that episode-like descriptions of a robot’s behavior were used when children were told to deal with complex tasks, or when they were confused and unable to understand complex patterns in robotic behavior.

It has been argued that children have more difficulties explaining the behavior of a robot than to program such behavior (Levi & Mioduser, 2007). However, evidence in the literature is not conclusive. There are studies emphasizing preschool children’s difficulty in reasoning with rules, thus causing their use of scripts rather than rules to describe a robot’s behavior (Flavell et al., 1993). In contrast, other studies show that experience with a facilitating robotic environment supports children’s use of rules (Bers & Portsmore, 2005). Children who were only required to explain the robot’s behavior used, as expected, more scripts and fewer rules to represent the robot’s behavior, while children involved in programming were able to construct rules even if they could not express and describe completely their complexity (Mioduser, Levi & Talis, 2009). Hoyles, Noss, Adamson, and Lowe (2001) found that children aged seven to eight used a formulaic rule and a psychological explanation of a robot’s behavior, but when involved in programming tasks, they described the events in terms of complete rules. Another study reinforces these conclusions indicating that the construction of rule-based behavior using a tangible-programming environment helps children stretch their cognitive skills (Mioduser, Levi, & Talis, 2009).

It is often seen in the literature that programming is a significant factor that encourages children's comprehension of rule-based behavior. In the study by Hong, Chijun, Xuemei, Shan, and Chongde (2005), children from three and a half to four and a half years old, had to use one rule: "If... then..." for one-dimensional tasks. For two-dimensional tasks, the children had to focus on two preconditions (i.e., "If... then... if... then..."). For three-dimensional tasks, the children had to focus on three preconditions. These situations obviously demand complex cognitive processes. The more dimensions, the more sophisticated the cognitive process involved indicating a development path. Most three-and-a-half year-olds could refer to a simple rule (If... then...). This reinforces earlier studies in which young children can only focus on one dimension. Another study that examined children's perspectives regarding artifacts (Siegler, 1986) indicates that young Children-Pre-schoolers' can deduce complex explanations regarding behaving artifacts, but the number of rules they can connect by themselves with complex behavior is limited to one at a time. The conclusion that children can only concentrate on one dimension is thus strengthened further.

In cognitive complexity and control theory, complexity is measured by the number of levels in the rules. For example, three-year-old children can cope with the formalization of "If red, then...", "If blue, then..." But, if another dimension is added, such as "a car", This is already a very serious difficulty. The more complex the rule system, the more difficulty the children will have in relating to several dimensions. As children grow older (Maturity age), they can cope increasingly with several concurrent dimensions, and their cognitive ability consistently improves (Hong et al., 2005; Siegler, 1986).

The complexity level is an important component of the tasks in this study. When children are asked to explain a particular event or situation, they first act intuitively, and only later recognize a rule characterizing the artifact's behavior. Despite this, the two systems (intuitive and conscious) are at times integrated, and therefore children seldom need to maneuver their way between them. The experience-based reflection and inference system about real-world events develops earlier than the abstract and generalizable rule-based one. Children have everyday knowledge and they react based on their own experience (Levi & Mioduser, 2008). Moreover, very early children can use rules. Four years old can already use a rule construct ("if... then...") and to a limited extent, two combined rules ("If... then... and if... then...") to explain and/or generate an artifact's behavior.

In summary, there are different theories and evidence regarding children's ability to use rules regarding the behavior of a robot interacting with a changing environment. Piaget (1967), in his study regarding scientific causation, argues that young children will find it difficult to think abstractly. Later studies suggest that temporary structured events will be described more as a script than as abstract rules (Flavell et al., 1993). Current studies show that children can process and use knowledge acquired by observation and active participation in solving a task to predict, plan and construct rule structures to program a robot's behavior (Mioduser, Levi & Talis, 2009). Very few studies in the past have dealt with the issues of the importance of programming at an early age as a tool for learning and cognitive development.

This study attempts to examine the contribution of young children's involvement in programming processes to promote appropriate perceptions of behavior control representations. Our main research question was:

Which representational structures of control (e.g. script, episode, rule) young children (aged 5-8) use to represent the adapting robot's behavior, as a function of:

- Age group, discriminating between preschoolers and first graders.
- Complexity of the task, defined by the type and number of structural representations included, i.e., one rule, two rules, a rule and a routine.
- Type of involvement in performing the tasks, either as "explainers" or as "programmers" of the robot's behavior.

Methodology

Participants

Sixty-nine children participated in the study from 2 kindergartens and a school in a city of medium socioeconomic status in central Israel. Kindergartens in Israel are under the supervision of the Ministry of Education and are mandatory, starting at the age of five years old. They are mostly independent units and not part of schools. The participants' distribution was:

- 46 children aged 5- 6 years old, from two kindergartens,
- 23 children aged 6.5-7 years old, first graders.

Participants were divided into three groups by their involvement in performing the tasks: 23 **kindergarten** children "**programmers**" (they were asked to program the robot in the different tasks); 23 **kindergarten** children "**explainers**" and 23 **first grade** children "**explainers**" (requested to explain the robot's behavior in the different tasks).

Procedure

The study was conducted during eight months during the school year. The learning sessions were held during the preschool or school day. Children's performance and interviews were video-recorded. The observations were transcribed, and coding was carried out according to the categories determined for the study's variables.

Programming Environment

The robotic environment comprised a computer interface (Figure 1), a robot (built from Lego parts and the programmable brick), and a physical environment modified to meet the requirements of the various tasks. The programming interface used for this study, "Kinderbot", is a research and development tool created in the Science and Technology Education Center at Tel Aviv University (Talis, Levy & Mioduser, 1998). Programming is based on the use of icons allowing intuitive and simple definition of commands (e.g., single actions, sequences of actions, routines, rules) without

requiring writing or reading code. A menu of the different programming modes appears on the right-hand side of the screen, each mode allowing to define the robot's navigation procedures in increasingly complex manner. Complexity increases from a mode resembling a remote control for the direct manipulation of the robot's actions, through modes allowing the construction of linear programs, to modes allowing to formulate conditional statements linking between incoming information (from the sensors) and outcomes or actions, in various rule formats (e.g., half a rule, a whole rule, routines -chunks of actions- and two interrelated rules). The rules are actually configurations of icons representing the inputs of the different sensors, and icons representing possible actions (the possible navigation directions for the robot) arranged in a matrix.

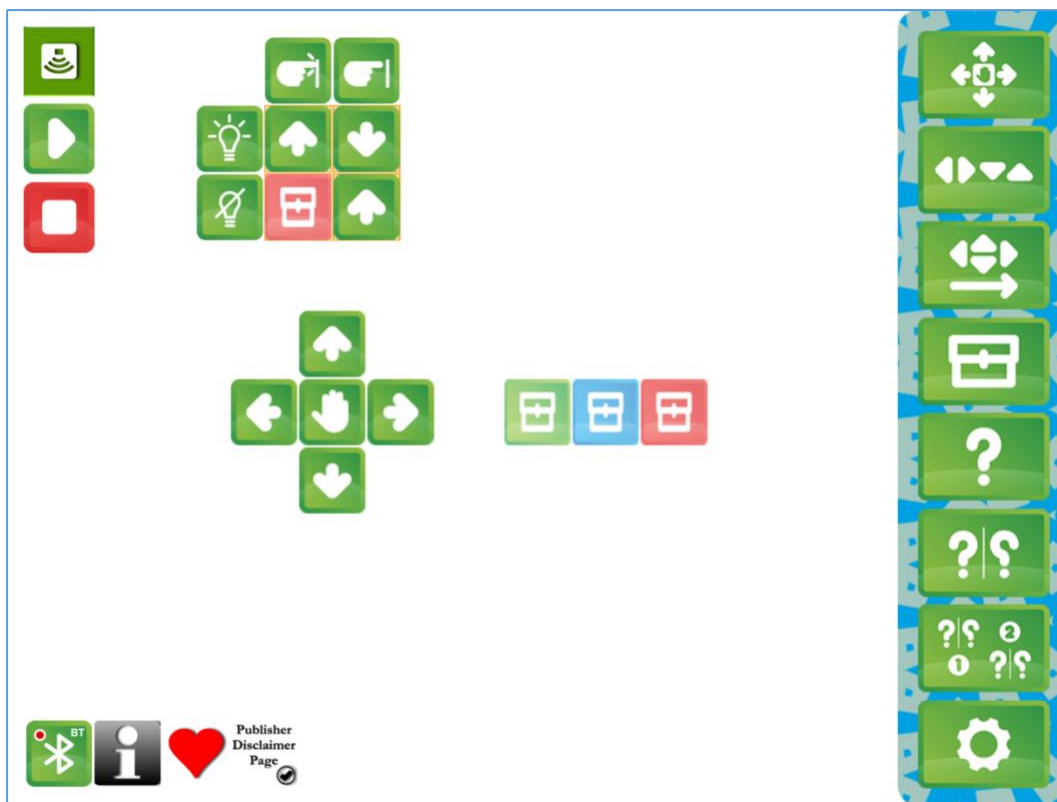


Figure 1: Kinderbot – the programming interface

Tasks

The children in this study performed three tasks of increasing complexity. The children in the “programming” group were required to plan and program the behavior of the robot. The children in the “explainers” group were asked to describe and explain the robot's observed behavior.

- One rule task: The Island. Frame story: the robot is on an island, and wanders in it without falling into the sea waters. The island is a black, elliptical surface, surrounded by a white surface. Robot's functioning: if the robot's light sensor detects darkness (the black color), it means that it stands within the island surface. If the sensor detects the white color the robot is now in the “sea area” and its path is corrected.

- Two rules task: The Bridge. Frame story: the robot must keep traveling on the bridge without falling into the raging waters. The environment is a white surface, with a black, winding, broad stripe in its center. Robot's functioning: if both light sensors detect the black color then the robot is on the bridge. If either the right or the left light sensor detects the white color, the robot is moving either to the right or to the left of the bridge (need to correct the path). If both light sensors detect the white color, then the robot is about to left the bridge – it should either stop or correct the path.
- Rule and routine: a maze with obstacles. Frame story: The robot must navigate a space avoiding obstacles, solid cubes scattered over it. Robot's functioning: Every time the robot hits an obstacle (touch sensor pressed), it runs a routine (several commands in succession) to escape it and continue its navigation.

Data analyses

The main unit of analysis were children's statements (verbal and enacted) as identified and coded following the transcription of the recordings of the programming and explanation sessions.

Quantitative and qualitative analyses were performed on the data collected.

Aiming to answer the research questions the following comparisons were performed:

- The effect of the **type of involvement** in the tasks on **preschool** children's perception of the robot's behavior: programmers compared to explainers.
- The effect of the **type of involvement** in the tasks on children's perception of the robot's behavior, as **age-dependent**: preschool programmers compared to first grade explainers.
- The effect of **age** on children's **explanations** of the robot's behavior: preschool explainers compared to first grade explainers.

Descriptive statistical analyses as well as group comparison tests were applied to the data collected for all research variables.

Research Findings

Research question: Which representation structures of control (i.e. episode, script, rule) young children (aged 5-8) use to represent the robot's adaptive behavior?

This question was examined as a function of age group, complexity of the task and type of involvement in the task as described above. In the following we present quantitative as well as qualitative accounts of the analyses performed in the different comparison configurations.

Comparison between preschool programmers vs explainers, as a function of task complexity.

We analyzed children's statements to unveil the way they refer to each of the representation structures. Thinking in rules represent the highest level of thinking, understanding situations in which there is a cause and an expected outcome.

Data in Table 1 indicate significant difference in the use of representational structures between the preschool groups in all three tasks. The **programmers** used mainly rules while the **explainers** used

mainly episode and script structures to represent the robot's behavior. The distribution of statements among representation structures by age and group for all tasks is presented in Table 2. Data in Table 2 shows that among the **programmers** reference to rules was dominant for all tasks. Among the **explainers** there is a high frequency of statements focusing on the usage of a script description in Task 1 (approximately 75%), and a considerable increase in the use of rules as the complexity of the task increased (60-65%). As tasks increased in complexity, also the explainers were required to describe the robot's behavior using more sophisticated structures. In the following, sample statements are presented, showing use of episodic description by the **explainers**:

A. (boy, aged 5, explainer): "I saw the robot's eyes and then I knew where he would go to."

E. (girl, aged 5, explainer): "He goes around everywhere. He goes here and here and here and here" (indicates circles inside the maze with her hand).

This was not the case with the **programmers** of the same age. There were no statements (for any task) describing the behavior as an episode. It seems that the design and programming

Table 1: Use of episodes, scripts and rules by preschool explainers and programmers

		Preschool programmers	Preschool explainers	t	p
Task 1	Mean	2.86	2.02	***9.03	0.0000
	Standard deviation	0.26	0.37		
Task 2	Mean	2.93	2.63	***3.55	0.0007
	Standard deviation	0.16	0.35		
Task 3	Mean	2.89	2.58	**2.74	0.0052
	Standard deviation	0.21	0.48		

Representation structures scores

1 - episode

2 - script

3 - rule

** p<0.01 *** p<0.001

Table 2: Distribution of statements (N=554) by use of representation structures, tasks, and activity (explainers or programmers) in the preschool group

	Rule		Script		Episode		Total	
	Preschool Programmers	Preschool Explainers	Preschool Programmers	Preschool Explainers	Preschool Programmers	Preschool Explainers	Preschool Programmers	Preschool Explainers
Task 1	94	10	12	53	0	8	106	71
	88.7%	14.1%	11.3%	74.6%	0.0%	11.3%	100%	100%
Task 2	80	67	10	32	0	4	90	103
	88.9%	65.0%	11.1%	31.1%	0.0%	3.9%	100%	100%
Task 3	93	46	14	26	0	5	107	77
	86.9%	59.7%	13.1%	33.8%	0.0%	6.5%	100%	100%

process requires, and facilitates, a broader view of the robot's functioning in terms of general and reusable rules.

Thinking about rules implies the capability to perceive the robot's behavior in terms of the causal relationship between a condition and an action ("if... then..." statements). Evidencing this perception, the programmers generated explanatory statements such as:

K. (aged 5.8, a girl programmer): *"If you see black, left, and if you see white, then left too. He needs to go straight on the black. He is going on the black. And going around. Every time he gets to the white, he goes back to the black. Because I wrote to him that he should go straight on the black and turn right... That is left on the white."*

L. (aged 6, a boy programmer): *"The two eyes see black and he moves forward. When one eye sees white... Right or left? He goes back to his path. On the other side, he also goes back to the path. When both eyes see white he turns around."*

L. doesn't actually employ the wording, "if... then..." but his mode of expression show a clear perception of the robot's behavior in all possible conditions (i.e., on the path or outside the path either to the left or the right) using several rules. It is evident that he understands the rules and their effect upon the adaptive behavior of the robot.

N. (aged 5.7, girl programmer): *"If he is free, then goes straight. And if he bumps into something, then a star (counts the steps back from the screen). And if he is free, straight forward. And then a star. It's hard... (Examines the robot). If he goes straight and gets stuck, then he goes here and here (moves the robot). When he bumps into something, he goes*

backwards and turns left. And dances like a star. He goes left, went backwards, and turned around until he got here (to the opening) and left..."

N. verbalizes the program. The task is very challenging and therefore N does a reflective process while planning. She understands the framework of rules and uses it to create a program with rules and a "withdrawing" routine (packed under an icon – the "star") due to which the robot manages to exit the maze.

The examples show that programmers understand the robot's behavior as a-temporal and repetitive process. The use of the words "all the time...", "goes back there...", "every time..." make it clear that the robot's behavior recurs whenever the defined condition is met.

Comparison between preschool programmers and first grade explainers as a function of task complexity.

Data in Table 3 shows that the performance of the **preschool-programmers** is significantly higher than that of the **first-grade-explainers**, for all three tasks. Preschool programmers generated representations of the robot's behavior using rules, while the first-grade explainers used mainly script-based representations.

Results of the qualitative analyses summarized in the distribution of statements are presented in Table 4, supporting the quantitative observations. The main representational structure used by first-grade-explainers is the script for most tasks. In Tasks 2 and 3 the frequency of use of scripts is similar to the use of rules. These figures show that first graders understood the robot's behavior mostly as a repetitive pattern or sequence of actions, rather than as ad-hoc decision making pending on conditions.

A sample statement showing the use of a script among the first-grade-explainers:

A. (aged 7.2) explains: "... *He began from here (indicates the start of the bridge) and from here (indicates the junction).*"

This does not apply to the preschool-programmers. They did not use any statements that indicate use of episodes or scripts to describe the robot's behavior while programming. They use rules more often than the first grader explainers.

Following is an example of the terminology used by the programmers for defining the rules that comprise the entire program required for the robot's functioning in the third task (in the form of a matrix of four condition-action pairs):

Table 3: Use of episodes, scripts and rules by preschool-programmers and first-grade-explainers

		Preschool programmers	First grade explainers	t	p
Task 1	Mean	2.86	1.97	***7.38	0.0000
	Standard deviation	0.26	0.52		
Task 2	Mean	2.93	1.94	***7.02	0.0000
	Standard deviation	0.16	0.65		
Task 3	Mean	2.89	2.01	***5.76	0.0000
	Standard deviation	0.21	0.71		

Representation structures scores

1 - episode

2 - script

3 - rule

*** p<0.001

Table 4: Distribution of statements (N=605) by use of representation structures, tasks, and activity-type (explainers or programmers) in the preschool-programmers and first-grade-explainers groups

	Rule		Script		Episode		Total	
	Preschool Programmers	First grade Explainers	Preschool Programmers	First grade Explainers	Preschool Programmers	First grade Explainers	Preschool Programmers	First grade Explainers
Task 1	94	14	12	38	0	8	106	60
	88.7%	23.3%	11.3%	63.3%	0.0%	13.3%	100%	100%
Task 2	80	31	10	38	0	22	90	91
	88.9%	34.1%	11.1%	41.8%	0.0%	24.2%	100%	100%
Task 3	93	63	14	56	0	32	107	151
	86.9%	41.7%	13.1%	37.1%	0.0%	21.2%	100%	100%

Y. (aged 5.7, programmer): “If the two eyes see black, he will go straight on. If they both see white, it will go backwards. If one eye sees white and the other black, then right. And the second side – left. If one eye sees white and it turns and goes to the black...”

The wording by Y. unveils a highly sophisticated capability to cope in concrete terms with four Boolean configurations of the values incoming from two sensors, i.e., sensors a and b “see” white;

sensor a “sees” white and sensor b black (a and not-b); sensor a “sees” black and b white (not-a and b); both sensors “see” black (neither a nor b). Kindergarten programmers used mainly rules, either while programming or while explaining the robot’s behavior.

Comparison between preschool-explainers and first-grade-explainers as a function of task complexity.

Table 5 compares between the two groups of explainers regarding the representation structures used by the children. Significant difference between the groups was observed in Tasks 2 and 3. It can be seen that the preschool-explainers used significantly higher representation structures in their explanations –i.e., scripts and rules– than their peers first graders. The research literature indicates that reasoning based on cause and effect, or reasoning according to rules, is not characteristic of preschool children’s reasoning. It could have been expected that specifically among the first graders –average age of 7– their explanations would comprise a significant number of representation structures based on reasoning according to rules. However, analysis of their statements shed light on their frequent use of episodic and script-like structures in their explanations.

Table 5: Use of episodes, scripts and rules by preschool-explainers and first-grade-explainers

		Preschool explainers	First grade explainers	t	p
Task 1	Mean	2.02	1.97	0.35	0.7295
	Standard deviation	0.37	0.52		
Task 2	Mean	2.63	1.94	***4.44	0.0001
	Standard deviation	0.35	0.65		
Task 3	Mean	2.58	2.01	**3.17	0.0028
	Standard deviation	0.48	0.71		

Representation structures scores

1 - episode

2 - script

3 - rule

** p<0.01 *** p<0.001

Table 6 shows the representational structures used by participants in both groups of explainers. About 20% of first graders’ statements indicated the use of episodes, whereas only about 7% of preschooler’s statements refer to an episodic description. The first graders’ use of episodes increases when required to cope with more complex tasks, or when they got confused observing the robot’s behavior and were unable to notice a particular pattern characterizing it.

The findings indicate an increase in the first graders' use of rules – from 23% for Task 1 to 41% for Task 3. The trend is similar with preschoolers – from 14% for Task 1 to 60% for Task 3. In this complex task, the robot's behavior triggered explanations based on the formulation of rules, particularly among the preschoolers.

Table 6: Distribution of statements (N=553) by use of representation structures, tasks, and activity-type (explainers or programmers) in the preschool-explainers and first-grade-explainers groups

	Rule		Script		Episode		Total	
	Preschool Explainers	First grade Explainers	Preschool Explainers	First grade Explainers	Preschool Explainers	First grade Explainers	Preschool Explainers	First grade Explainers
Task 1	10 14.1%	14 23.3%	53 74.6%	38 63.3%	8 11.3%	8 13.3%	71 100%	60 100%
Task 2	67 65.0%	31 34.1%	32 31.1%	38 41.8%	4 3.9%	22 24.2%	103 100%	91 100%
Task 3	46 59.7%	63 41.7%	26 33.8%	56 37.1%	5 6.5%	32 21.2%	77 100%	151 100%

Examples of statements showing use of **rules** among first graders and preschoolers:

A. (aged 5.7, a boy preschooler): *“On black, he needs to go on the black, right, and stop when the eyes see white. And if one eye went, then he goes back. The eyes see white, one sees white and one sees black, and then it turns to the black.”*

Y. (aged 7.4, a boy first grader): *“You wrote to him if you bumped into something. Then don't stay in the same place. Go back to some other place. And if you bump into something. Then go to another place. If you don't bump into something, then great!”*

It seems that both the first graders and preschoolers are able to generalize and generate abstract descriptions while explaining the robot's behavior. They are able to refer to cause and effect situations when they see the complex behavior of the robot, which is not perceived necessarily as a repetitive pattern. However, at the same time, in Task 3 we observed more frequent usage of the rule representation structure among preschoolers - 60% as opposed to only 41% among first graders (we should note that these are findings by two groups of “explainers”, who were not actively involved in programming – we will expand on these findings in the discussion section). We should note that for the explainers' groups, both preschoolers and first graders, data analyzed showed an increase in the use of the more sophisticated structure -rule- as task complexity increased. Tasks 2 and 3 complexity was evident - use of two rules in task 2 (meaning an increase in

variables' value configurations) and a routine plus a rule in task 3 (requiring definition of the routine and its integration as the "action part" in the rule). These tasks demanded a more thoughtful reflection even for the non-programmers, in order to generate satisfactory explanations of the robot's complex behavior. Within the explainers, we found more frequent use of the rule construct among the preschoolers – the interpretation of this particular finding will be presented in the discussion section.

Overall summary of our observations

Summarizing our quantitative and qualitative observations, the study findings indicate that:

- Programmers seem to perceive the robot as a system, and even more – as a rule-based system.
- First-grade-explainers mostly understood the robot's behavior in terms of a temporal sequence of actions – expressed either as episodic or script-like explanations.
- In contrast, preschool-explainers demonstrated higher understanding than their peer first grade explainers, using rules significantly as part of their explanations.

Discussion

N., a preschooler: *"That if he doesn't touch, then he won't dance. And if he touches, then he will dance"*

The ability to understand, generate and apply condition-action constructs by young children has been a matter of research for a while, not solely connected with robot programming (Mioduser, Levi & Talis, 2009). Studies show inconclusive evidence regarding children's ability to form rules in general, and in relation to a robot's behavior in a changing environment in particular. Piaget (1967) argues in his studies on scientific causation that preschool children have difficulty in perceiving abstract cause/effect relationships in the physical environment. In a series of studies conducted by us for several years, we aim to examine the effect of children's actual involvement in planning and programming an artifact's functioning on their understanding of complex adaptive behaviors and the abstract constructs underlying it.

The findings of this study showed that **preschoolers who program** the robot are able to grasp the complexity of the observed/expected behaviors of the robotic device and formulate it in the form of a-temporal and general rules. We found that they do not use "episodes" at all to represent the behaviors, and use "scripts" minimally (see data in Tables 3 and 4). The use of rules among the **programmers** is dominant for all tasks – both easy and difficult. The differences with the other research groups were significant for all tasks implemented (data in Table 3).

The planning and programming processes demanded from the children to develop a broad vision of the robot's behavior, to identify regularities and repetitive chunks of action, and to formulate all these in the form of general rules of behavior rather than ad-hoc linear episodic descriptions. Although many studies have shown that preschool children have difficulties in using a coding interface that demands formalization of the rules, i.e., defining If...Then... constructs, this study

reinforces our previous findings showing a different picture: Children can use abstract tools to program a robot's actions and even explain its behavior in terms of an abstract rule or even two interacting rules (Levi, & Mioduser, 2008).

Regarding the first graders explanations

Examining the representation structures used by the first graders', we found that they use "episodes" more than the preschoolers. The question that arises is what brings first graders to use the situation specific and linear representation as construct to describe the robot's behavior, despite their developmental advantage over the preschoolers. Moreover, the first graders' use of episodes increased when they were required to cope with a complex task or when confused and unable to pay attention to particular patterns characterizing the robot's behavior. It appears that they focus on the robot, noticing its actions each at a time, while ignoring the environment traits within which it is acting – thus ignoring cause-effect relationships. We suggest two possible explanations for the older children's performance.

The first explanation relates to the schooling/curricular acculturation processes. Existing research provides evidence on the contribution of actual experimentation with technologies and involvement in performing technological tasks to the understanding and learning of concepts and skills related to the artificial world. However, school curricula usually encourage more traditionally academic learning than active involvement in experimentation, doing, and constructing processes than kindergarten curricula. Kindergarten curricula comprises learning environments and tasks aimed to encourage children to become involved in creative processes, to cope with complex processes, to ask questions and look for answers, while offering ample space for exert curiosity and learn by doing and constructing. In contrast in school curricula there is a decrease in tasks involving manipulation of objects, working with building kits or implementing solutions for open ended real-world problems (e.g., not structured into the learning materials in use). Perhaps, the focus on structured tasks leading systematically to the attainment of pre-established goals (e.g. concepts, skills, "right answers") characterizing most learning processes at school, makes difficult for the children to explore unstructured situations related to objects and systems in the world, and to generate appropriate insights and abstract explanations concerning their complex behavior. Ways of thinking extensively supported by the flexible, experimentation-based and open-minded kindergarten's curricula and learning culture gets gradually replaced by the structured, academic-oriented and "right-processes"- "right-answers" curricula and learning culture in school. Obviously, maturation and developmental changes between the two age-level groups do exist, but these alone do not warrant higher level perceptions and understanding of the observed phenomenon – in this case robots' behaviors. Along similar lines of explanation, previous research stresses the role of developmental paths, experience and pedagogical approaches on children's perceptions and thinking about complex problems and designed objects in the environment (e.g., Ebel, Hanus & Call, 2019; German & Defeiter, 2000).

Following the above, our second explanation relates specifically to the effect of being involved in constructing the robot's behavior on children's development and consolidation of rule-generation and inductive reasoning skills. In a previous study, we examined kindergarten children's ability to

distill abstract rules while programming a robot's complex behavior (Mioduser, Levi & Talis, 2009). We discussed there the situation faced by the young programmers in which the abstract rules governing the robot's behavior are embedded in a concrete physical object acting in response to environmental features. The robot's behavior can be manipulated, observed, programmed and debugged in endless iterations. "This is the realm of thinking processes we refer to as the realm of "concrete-abstractions", in which recurring cycles intertwining the symbolic and the concrete are exercised by the child while abstracting schemas for understanding the robot's behavior." (pp. 32). First graders, who did not go through the rule-construction process in all its faces but were asked only to describe the robot's behavior, were not able to unveil the deep a-temporal and general structures underlying the robot's adaptive behavior.

The results of this study strengthen our previous observations on the connection between young children's involvement in programming and cognitive gains concerning their understanding of the complex functioning of artifacts. Within the concrete-abstractions realm, children at a young age are able to explore complex processes, discover regularities and formulate these using formal descriptions. The support of a developmentally appropriate coding environment is crucial. In our current and planned research, we aim to deepen our understanding of children's coping with more sophisticated robot behaviors (e.g. the use of routines or procedures embedded in the rules, or the use of several interacting rules). Our goal is to gain a better understanding of children's inductive and rule thinking when facing dynamic adaptive processes – so common in real world events.

The conclusions of this study are consistent with the conclusions of other studies conducted by us in recent years examining the importance of young children's experience in programming processes (Spektor-Precel & Mioduser, 2015; Rave, 2017).

At the implementation level, we have already integrated the knowledge gained in the development of learning environments and experiences for kindergarten children, as well as teacher training activities. We continue to develop the KiderBot programming language and environment which is already in use in kindergartens in Israel.

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Working in Groups on Practical Engineering Activities with Young Children

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Abstract

Australia has a long-standing interest in fostering innovation capabilities to drive its future prosperity. However, it has only been in recent years that an emphasis on developing these capabilities has been formally extended into the classroom through the introduction of the Australian Curriculum Technologies. In 2017, the State Government of Victoria implemented its version of this national curriculum for the Technologies domain. For educators, this recent implementation could be considered problematic, for unlike the traditions of literacy and numeracy, methods to assist classroom teachers in diagnosing developmental indicators, for applied spatial problem-solving among children appears to be lacking in the Technologies area. Without such methods of diagnosis, it can be argued that teachers may struggle to develop appropriately targeted lessons, that demand of the student, the ability to comprehend applied spatial problem-solving, such as with hands-on engineering activities. Our research aims to investigate how a child's applied spatial inferential reasoning capabilities, vary by developmental age. To answer this question, we have adopted a two-stage process. Stage One involves a pilot study testing and refining the key research instruments. Stage Two incorporates the main study involving a larger number of participants. This paper summarises early insights from a mixed-method pilot study involving 15 students (9 boys, 6 girls) from Years 3-12. Students enrolled in this study undertook one of three hands-on problem-based engineering activities categorised as simple, complicated or complex; working in small groups of three. We noted that gender makeup of the group, and age levels of participating students appeared to be variables that impacted on organisation, communication and the solution produced. These preliminary observations assisted to refine the key indicators for observing students in preparation for the main study. Key interests in this study include the student's capacity for inference-making and abstraction with respect to spatial problem-solving. A review of the relevant literature and the need for further research in spatial reasoning is discussed.

Keywords

Spatial reasoning, inferential reasoning, child development, STEM, gender education, Technacy, Technologies curriculum, innovation capabilities.

Introduction

As far back as 1996, the need to build innovation capabilities in our students was acknowledged when the Australian Science, Technology and Engineering Council's Foresight Report recommended clearly that Australia had to pursue and incorporate innovation into both the primary and secondary school curricula, with Technacy as its suggested framework (ASTEC, 1996). Technacy is defined by the Australian Standard Macquarie Dictionary as the technological equivalent to literacy and numeracy, with an emphasis on the holistic understanding and application of technology, whereby environmental and social contexts are

considered (Seemann, 2009; Technacy, 2017). The introduction of the compulsory Technologies curriculum in Victoria, Australia from Foundation to Year 10, in 2017 (State Government of Victoria, 2016), had as an objective the development of a skillset whereby students would “learn how to use technologies to create innovative solutions” that would meet both current and future needs (Victorian Curriculum and Assessment Authority [VCAA], n.d.). The Technologies curriculum demands applied spatial inferential reasoning beyond common engaging hands-on engineering activities (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2012). Of key concern to the authors of this paper, is the dearth of research literature that guides the teacher in how to identify student progression in their educational growth, when they are engaged in applied spatial inferential reasoning. Developing an evidence based approach to identify common milestone behaviours, against higher order applied spatial inferential reasoning in tackling the engineering concepts in the Australian Technologies Curriculum, offers the potential for classroom years in primary and secondary schools, to better manage learning challenges and differentiation for student centred pedagogy.

The research presented in this paper seeks to provide a preliminary insight, through early observations of a Stage One Doctoral Pilot study, into how spatial inferential reasoning capabilities vary with developmental age and the complexity of hands-on STEM activities. While the pilot research involved students from both primary and secondary schools, as part of a comparative case study, this paper will predominantly focus on students working technologically in the primary classroom. In addition, we also explore how this collaboration works in mixed gender groups. The early observations made from this pilot will inform the limited discourse on the use of instruments, specifically hands-on engineering activities, in eliciting spatial reasoning capabilities in a collaborative setting, which could assist teachers in scaffolding activities to suit students in the engineering genre of the Technologies curriculum. The Technologies curriculum is sub-divided into two subject areas: Design and Technologies; and Digital Technologies. The Technologies curriculum is a very broad area within both the Victorian and Australian Curriculum. To put in context, the Australian Curriculum provides teachers with a clear understanding of what students should learn, regardless of where in Australia they live or which school they attend (ACARA, 2016). However, under the Australian Constitution, it is the State and Territory Governments that are responsible for schools. They make decisions in the translation of the Australian Curriculum into the curriculum that is experienced by students in Foundation to Year 10. As the States and Territories have not agreed to common curriculum and assessment in Years 11 and 12, each jurisdiction has devised its own. Since this paper will focus on the capability of students to abstract and infer in the engineering genre of the Technologies curriculum, the Design and Technologies subject will be the focus.

Spatial inferencing in middle childhood

According to the National Research Council (1984), middle childhood is a period between the ages of 6 and 12. This is a time of tremendous developmental growth, which spans the six main developmental categories of physical and brain development; language development; cognitive development; social development; emotional development; and moral development (Duchesne & McMaugh, 2019). The ability to “reason through scenarios” is a noted observation in middle childhood (Knight & Lee, 2008, p. 146).

Abstraction and spatial inferential reasoning are key to imagining a way for engineering concepts to work in real time applications (Contero, Naya, Company, & Saorin, 2006). Spatial inferential reasoning is seen as being necessary for developing the capability in students of thinking and acting as innovators in the engineering genre of the Technologies curriculum (Kell, Lubinski, Benbow, & Steiger, 2013; Khine, 2017). A working definition of spatial inferential reasoning is taken as the “mental processes of representing, analysing, and drawing inferences from spatial relations” (Uttal, Miller, & Newcombe, 2013, p. 367). For example, consider an individual who observes an engineering structure such as a machine or device of some sort and, is able to rotate mentally that three-dimensional object, or can visualise the machine working in three-dimensions. Such an individual is demonstrating a spatial skill; they are forming abstract inferences of how they imagine the object or mechanism to work and be positioned in relative terms in space.

According to Piaget’s model of cognitive development, a child’s intellectual development progresses through a series of stages that are characterised by qualitatively different cognitive processes (Goswami, 1998). As abstraction and spatial inferential reasoning are dependent on cognitive ability, the work of Piaget provides a foundation to this study, with student participants selected from two distinct stages of Piaget’s framework: concrete operations; and formal operations. For the purpose of the Stage One Pilot study, students were randomly selected from three cohort groups: Years 3 and 4; Years 7 and 8; and Years 10 to 12. Focusing on the junior group drawn from students in Years 3 and 4, with an age range of 7 to 9 years of age, these students are considered in middle childhood and progressing from the ability to think about concrete realities to more formal operational reasoning where they think about abstract possibilities. According to Piaget’s stage model, these students should be showing some early signs of the ability to abstract and infer. However, this can be considered a contentious point, as Gopnik (2012) argues that contrary to Piaget’s view, children exhibit elements of abstract reasoning, albeit “basic inductive processes of science” (p. 1623) that are typical of scientific experimentation.

Collaboration between students

Often engineering and STEM work is conducted in a team, and the ability to communicate abstract ideas is essential. Developing innovation capabilities in schools goes beyond simply transmitting knowledge. As learning is a complex social process, it requires students to work collaboratively across multiple contexts (Vygotsky, 1978). Not surprisingly, an increasing number of educational jurisdictions are including collaboration as a required skill in their curriculum (Tarbutton, 2018). Social communication, and how this can progress cognitive abstraction, is the second of the two qualities that is examined in this pilot study and the subsequent main study.

Children in middle childhood are still developing the skill of working collaboratively (Baines, Blatchford, & Kutnick, 2003). A common scenario can be observed where children are working alongside each other at a table, but with no clear evidence of the children exchanging and sorting their ideas to develop a logical solution to meet the objectives of a group task they have been given (Baines, Blatchford, & Kutnick, 2003; Kutnick & Blatchford, 2014). With increasing maturity and further development of their social skills, the nature and the level of social interaction becomes more sophisticated and complex. As Rusk and Rønning (2020) have observed, there remains scope for further research involving group-work, such as the social

organisation of groups, and the skills needed for students to engage effectively in group-work, through sharing and trading ideas.

The notion of parallel play has been reported in the early pre-school years, where children can be observed playing side-by-side but with no real interaction or cooperation between the children (Bakeman & Brownlee, 1980; Howes & Matheson, 1992). As the child continues to develop, this individual play is increasingly replaced by one that is more cooperative and social (Bakeman & Brownlee, 1980). Of interest to this study is therefore the nature and level of interaction between children working technologically in small groups in the primary classroom. One hypothesis is that younger students (i.e. the junior cohort) will not exhibit the level of trading of ideas in a group situation, as is expected with the older students (i.e. the senior cohort).

Children and self-esteem

In any problem-solving activity, negative emotions could be experienced if students are given a task that is beyond what Vygotsky (1978) referred to as their zone of proximal development. Logically, this would be expected to impact on a student's ability to function (Boekaerts, 1993). It would have an adverse impact on the student's sense of self, such as their self-esteem. In an Engineering class, this can result in the student throwing their hands up in despair; possibly resulting in a feeling or sense of failure, as would be suggested by the work of Erikson (1968). Table 1 provides a comparison of three developmental indicators, including Erikson's psychosocial stage model for our Junior Group of students taken from Year 3 and Year 4, and the Senior Group taken from Years 10 to 12.

Table 1: Comparison of three developmental indicators

	Years 3 and 4 (Junior Group)	Years 10 to 12 (Senior Group)
Piaget's cognitive development	Students can mentally manipulate and think logically about objects, and see from another person's point of view	Students can think abstractly, develop hypotheses, and use a systematic approach to solve problems
Social interaction	Developing	Relatively advanced / students trading ideas
Erikson's stage of psychosocial crisis	Industry vs Inferiority	Identity vs Role confusion

Self-esteem describes our sense of worth as a person (Kille & Wood, 2012) and it is an important element in children's overall wellbeing (Orth & Robins, 2013). Closely associated to self-esteem is the concept of self-efficacy, which is concerned with an individual's belief about their ability to perform a task successfully (Bandura, 1994). For this reason, self-efficacy is often referred to as our can do attitude of self, and is influential in how we feel, think and act (Bandura, 1994). Potentially we can damage students' self-efficacy, so students go from a can do attitude to a can't do attitude or developing feelings of I'm dumb. A feeling of inferiority develops when students experience a negative event in the classroom, which can then lead to feelings of self-doubt or being a failure (Erikson, 1968). Teachers play an important role in reinforcing a sense of competence in primary school students. However, in the Technologies

curriculum, hands-on engineering activities can be hit or miss, as the experience of a teacher may determine whether a suitably challenging activity is implemented in the classroom (Crismond, 2013). When developing hands-on engineering tasks for students, it is important that they be provided with appropriate challenges that are realistic; otherwise, the potential exists for students to feel like failures (Martin, 2010).

Gender differences

Developmental milestones are not only dependent on age, as gender also plays a role. This is evident from neuroscience research, which reports that the cerebral cortex, cerebellum and the corpus callosum develop at different rates in boys compared with girls. For instance, the cerebral cortex reaches maximum size in boys by age 15, compared with age 11 for girls (Giedd & Rapoport, 2010). A comparison of the corpus callosum (which connects the two hemispheres of the brain) is reportedly thinner in boys compared to girls of the same age (Francis, 2006). This is important to note, as the cerebral cortex is believed to play a significant role in cognition, perception, language and executive function (Lerner & Schenk, 2014), whereas the corpus callosum is responsible for integrating key motor, sensory and cognitive functions across the two hemispheres (Francis, 2006). For this reason, the role of gender is considered important when examining key cognitive functions such as spatial inferential reasoning, creativity, critical thinking and communication. This is especially relevant in light of research, which suggests that teachers are often unprepared to address the number of gender-related differences and issues that are found in the classroom (Major & Santoro, 2014).

Research Questions and Methodology

The Stage One Pilot project, which is the basis of this paper, was conducted to test, refine and develop the key indicators for observing students and their ability to reason in a spatial inferential manner. The revised indicators and methodology were an outcome of this pilot study, and will be tested in the second phase of this study involving a larger group of participants.

For the pilot study, the researchers set out to answer the following two questions:

Can the hands-on engineering/STEM activities developed, elicit a demonstrable difference in spatial reasoning between the three groups of junior school, middle school, and senior school students?

What impact does gender have on group structure, task progress and task completion when completing hands-on engineering activities?

A small-scale mixed-method comparative case study involving three different cohort groups from the same co-educational Early Learning to Year 12 independent inner-city school, informed this study. A summary of the groups is presented in Table 2.

Table 2: The three student cohort groups that formed the Stage One Pilot study

Junior Group	Middle Group	Senior Group
Years 3 and 4	Years 6 and 7	Years 10 – 12
Age range 7 to 9	Age range 10 to 12	Age range 15 to 18
Six participants	Six participants	Three participants

Students from within each cohort level (i.e. junior, middle and senior) were randomly assigned to a small mixed-gender group comprising of three students for completing one hands-on engineering activity. Five groups in total formed the basis of this pilot study, with two groups from junior school, two from middle school, and one from senior school. Each group, of exactly three students, undertook one hands-on engineering challenge, with each group of three randomly assigned to complete one of three engineering challenges. The three engineering challenges were of varying level of complexity: simple, complicated or complex as determined by the researchers. These challenges are shown in Figure 1. The three hands-on engineering activities identified for this research are all practical tasks that are well suited to engaging students with hands-on problem solving in the Design and Technologies (Engineering) domain of the Victorian Curriculum.

Students were video- and audio-recorded. They were asked to think aloud to capture deeper insights into their strategies and logical thought processes. As the students built their simple, complicated or complex machine, non-verbal behaviour and cues were captured (Cohen, Manion, & Morrison, 2011) in addition to their verbal reasoning via the think aloud approach. The product of each activity was a machine that had been built according to the design brief or a set of provided instructions. This then became a physical artefact. The students' ability to abstract in building the machines included quality of the artefact and meeting the design brief. The quality of the artefact was assessed as either a viable solution (i.e. the machine worked as expected), or a non-viable solution (i.e. the machine did not function as intended). Other measures observed/captured included: the level and quality of the social interaction within the group, and the nature of verbal and non-verbal communication during the activity. Any difficulties that students were experiencing, such as struggling to meet the objective of their hands-on task, could manifest in a change of attitude toward the task and/or a change in their behaviour (Greene, 2018). This could provide insight into Erikson's psychosocial model from a Technologies perspective.




Simple Challenge	Complicated Challenge	Complex Challenge
<p style="text-align: center;">Windmill</p>  <p>Complete set of instructions given, with the precise number of parts included in the kit</p>	<p style="text-align: center;">Tower Crane</p>  <p>Pre-determined number of steps missing from the set of instructions; extra parts included</p>	<p style="text-align: center;">Steerable Boat</p>  <p>Design brief given with choice of components; but one key component not evident</p>

Figure 1: The three hands-on engineering activities of varying complexity

Collecting data through the kits

In developing the hands-on diagnostic engineering kits, several factors were considered, the most important of these being:

- student safety;
- time required for students to attempt/complete the activity (to minimise amount of time that students are withdrawn from classes); and
- cost of hands-on resources.

With the comparative case study involving young students from Years 3 and 4, student safety was paramount. For this reason, the simple and complicated hands-on activities adopted LEGO's use of interconnecting plastic components. The simple and complicated kits are shown in Figure 1. For the complex task, students were provided with a kit of parts that included pre-assembled components, such as small alligator clips soldered to ends of wires, which in turn were soldered to motor terminals, solar panels and battery packs. This use of pre-assembled components reduced the number of tools that students needed to those readily available in the school classroom (e.g. scissors) and thus decreasing the risks.

Complexity levels presented by the kits

Complexity level: Simple

With respect to cognitive demand on inference making, this task is simple as the solution or end goal is given to the students. There is little that students have to imagine. The students are given the precise number of parts required to construct a machine, with a complete set of instructions provided. Each step is given in a mostly one-to-one mapping towards the solution. Thus, there is low demand to imagine the step, and no demand to imagine a working solution.

Complexity level: Complicated

In the complicated activity, more demand is placed on imagining the steps to a working solution. While students are provided the solution (or endpoint) in the form of a two-dimensional diagram, they are given an incomplete set of instructions, with several sub-steps deliberately removed. An intended further complication is that students are provided with more parts than needed to construct the machine. With several sub-steps missing, students are required to bridge the gaps, which demand some imagination to join either side of the missing steps. Success of this challenge is determined by whether or not the machine works as it was intended.

Complexity level: Complex

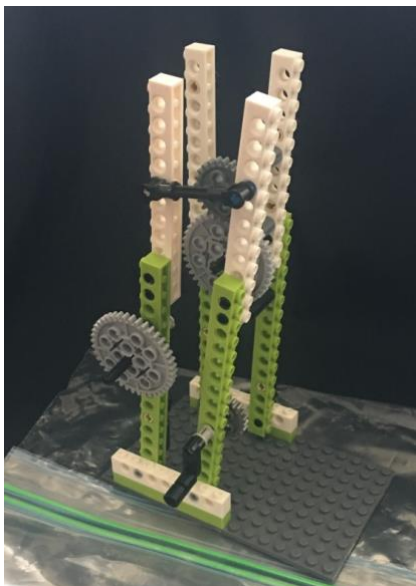
Unlike the simple or complicated activity, in this complex task the solution is not provided, however it is described in the form of a design brief. At least one solution will work. There are a number of abstractions that students need to make, such as, how the model boat will float or how it can be controlled remotely. Additionally, there will be other design decisions requiring students to draw upon their life experiences.

Analysis and Discussion of Early Observations

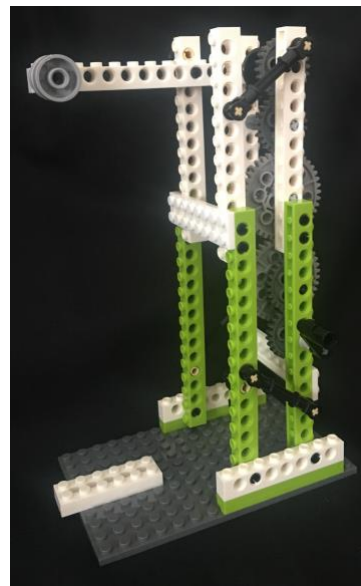
A summary of key observations from the Pilot Study with some detailed commentary are provided below.

Suitability of the hands-on research instruments

The research instruments developed in the form of three hands-on engineering activities of varying complexity and tested in this pilot study have the potential to elicit cognitive and social differences between the different aged cohort groups. In undertaking the complicated activity, junior students were observed to be working in parallel, with limited trading of ideas and little distribution of sub-tasks among this group of three, which resulted in a model that was partially constructed (i.e. unsuccessful build resulted). In contrast, the senior students approached the complicated task as a 'joint endeavour', working cooperatively to produce a machine that worked as intended and which satisfied the challenge requirements (i.e. successful build resulted). Figure 2 shows the junior group's attempt to build the complicated Tower Crane, which placed cognitive demand on the students to imagine the steps to a working solution given several construction steps were missing.



(a) Junior Group 1 end-result for Tower Crane



(b) Tower Crane as it should look

Figure 2: Complicated task – Tower Crane

Social non-task related discussion was a regular feature in the junior groups, with the boys prone to distraction that is more frequent and for longer, than the girls. Distraction within the middle-school students was minimal, with the senior students showing no inattention to the challenge task. One particular observation of note, which emanated from the boy-dominated junior group, occurred when one of the two boys stated "we're smarter in LEGO" to which the young girl retorted "we're [girls] smarter in English". This stereotypical discussion about contrasting gender abilities is similar to that reported by Bergin et al. (2018). This raises implications for teachers on how to handle gender stereotyping at the primary school level, especially in light of the under-representation of women in STEM-related courses (i.e. senior

high school and university) and employment in STEM careers such as engineering (Australian Academy of Science, 2019; Colette & Marjolaine, 2017; Kricorian, Seu, Lopez, Ureta, & Equils, 2020).



(a) Middle Group 1 and their completed Windmill



(b) Middle Group 2 and a partially built boat

Figure 3: The two artefacts produced by the middle groups

While the simple, complicated and complex activities seemed appropriate for eliciting spatial reasoning and levels of communication in a group setting, the question remained of how much time is reasonable to conduct these experiments without compromising the quality of data collection. As these activities were conducted as a research experiment, a nominal amount of time was determined by the researchers to ensure minimal impact on schools. The time allocated for each of the three activities - 15 minutes for simple; 20 minutes for complicated and 25 minutes for complex was insufficient for all five groups. Additional time was given to each group, with only one of the two middle group completing the construction of their machine. They were given an additional seven minutes to complete the simple Windmill machine, as shown in Figure 3. The senior group completed their complicated machine, though were given an additional four minutes. Extra time will need to be provided to participants in the main study.

Gender impact on group structure and collaboration

Girls took the lead role in both junior groups when solving the engineering problems, unlike the middle and senior groups where the girls were content to sit back and allow the boys to take the lead. The observations with the middle and senior groups is not surprising in light of the work by Major and Santoro (2014) who suggested that girls are “characterised by compliance, sociability, caring and empathy” (p.60) to solve problems. Further study is required in this area and will be a focus in the second phase of this study.

Another gender-related observation relates to the girl-dominated junior group (i.e. 2 girls, 1 boy). The girls exhibited a greater tendency to work collaboratively through communicating ideas and nominating individual tasks for each member to undertake. Conversely, the boy-dominated junior group (i.e. 1 girl, 2 boys) were prone to frequent distraction, despite the best efforts of the lone girl who provided words of encouragement and reminded the two boys that they were being assessed as a team. This comparison is shown in Table 3.

Table 3: Comparison of the two junior groups

Junior Group 1 (complicated task)	Junior Group 2 (complex task)
2 boys, 1 girl girl took lead role students were working primarily in parallel, with little evidence of trading/sharing ideas boys were distracted on many occasions, but as model construction progressed, they settled and focused on building girl attempted to provide moral support to the boys, but was concerned about failing at the task artefact produced shown in Figure 2 did not work as intended	1 boy, 2 girls girl took lead role some evidence of trading/sharing of ideas was present boy did as instructed by lead girl, but was distracted on a few occasions by the presence of the camera girls stayed on task throughout, though some social (non-task) commentary was present artefact produced met one of the three criteria (i.e. powered by electricity, but boat did not float and was not steerable)

The contrasting observations of the two junior groups raised the question: does the composition of having two girls in the group lead to effective collaboration amongst the team? These observations highlight the work of Rusk and Rønning (2020) and support their argument that further research is required to tease out the finer workings of these types of relationships in group activities. The impact of gender on group structure is a consideration that has been previously flagged by researchers, such as Kutnick and Blatchford (2014). Additionally, the argument that students need to develop a set of skills for effective, cooperative and collaborative work when students engage in group-based tasks (Kershner, Warwick, Mercer, & Kleine Staarman, 2014; Looijenga, Klapwijk, & De Vries, 2016) has also been a topic of research over the last few years.

Failure and self-esteem

The only girl in Junior Group 1 undertaking the complicated challenge remarked that she “finally failed a test”. This was not the intention of the complicated activity; however, it is a reminder of the importance students place on their self-esteem and self-efficacy. Ensuring that activities are not beyond a student’s developmental ability or beyond the zone of proximal development when activities are group-based with peers that are more knowledgeable, should help alleviate situations where students could develop the mind-set of not being smart enough. In this situation, teachers play a critical role, by providing encouragement, task scaffolding, and setting appropriate challenges in the classroom, all which can help build a sense of competence. While Orth and Robins (2014) indicate that self-esteem generally improves from adolescence to middle adulthood, the case is not clear with younger children, with some evidence identifying a number of factors that can contribute to a decline in a child’s self-esteem as they enter middle childhood (Harter, 2012).

The girl in Junior Group 1 believed that she was hamstrung by her two male peers and their inability or desire to work effectively as a team. She believed that she had the capability to complete the complicated task if she had been able to complete the task on her own. She was

the only one in the group concerned that some steps were missing, whereas the two boys were adamant that nothing was amiss and that they could complete the challenge. This observation, albeit from a pilot study, lends support to the arguments expressed by other researchers that students need to be taught to work collaboratively (Kutnick & Blatchford, 2014; Rusk & Rønning, 2020).

This study also flags an interesting possibility that girls possess a greater awareness for finer details. This could be attributed to their cognitive and brain development relative to boys of similar age. The main study will seek to investigate this dimension of spatial activity in both individual and group-work settings.

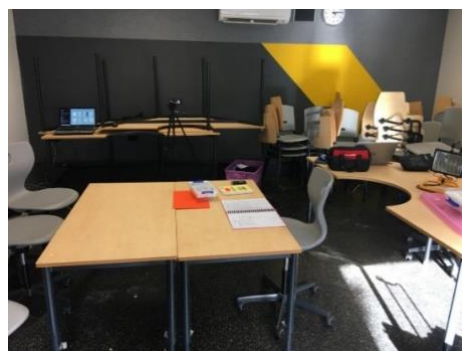
This observation further highlights a key dimension to engineering activities, both in the classroom and in the real world, that failure is a “normative condition in engineering” (Lottero-Perdue & Parry, 2017, p. 49). Failure is therefore considered an important aspect of teaching Technologies subjects such as Engineering. It is necessary for students to test and evaluate whether their design criteria have been met (Lottero-Perdue & Parry, 2017). The Framework for K–12 Science Education in the USA has incorporated failure analysis into their curriculum when teaching engineering concepts to primary school students (National Research Council, 2012). Such an emphasis is missing from the Technologies curriculum in Australian schools. Regardless, teachers should be encouraged to incorporate failure analysis within their teaching discipline.

Classroom effect on design decisions

It is important to consider the layout of the classroom environment when undertaking hands-on activities. Two junior groups were located in an Art Room which encouraged a level of experimentation in completing the complex task, with students actively considering materials commonly found in this type of room (e.g. cork) that would help satisfy the design brief (i.e. boat needed to float). A similar such level of experimentation was not evident in the traditional room setting. The two rooms used are shown in Figure 4. Incidentally, it was noticed that student distraction was minimal in the traditional room setting; however, this was not the case in the Art Room where the boys from the two junior groups were distracted most often.



(a) The ‘art’ room (junior groups)



(b) The ‘utility’ room
(middle/senior groups)

Figure 4: Classroom environment for student observations

Further research in spatial abilities

While this study draws upon the work of Piaget and his stage model of cognitive development, the work of Gopnik and Wellman (Gopnik, 2012; Gopnik & Wellman, 2012) in investigating the

spatial abilities of children needs to be considered, as the development of abstraction and spatial reasoning is not clear cut. Students that might be identified as possessing high spatial ability are not being recognised, as they do not necessarily demonstrate high ability in verbal or mathematical reasoning (Webb, Lubinski, & Benbow, 2007). Spatial abilities develop from birth (Mathewson, 1999), with evidence these abilities are “malleable and can be improved with interventions, enrichment and training activities” (Khine, 2017, p. 3). Nadelson, Seifert, Moll, and Coats (2012) argue that schools should place a greater emphasis on STEM education in the early years to help build student capability in the technology and engineering domains of the curriculum and to help build spatial abilities.

Conclusion

This Pilot Study provided a number of useful insights that are important for our preparations for the main research study. The research instruments used, specifically the simple, complicated, and complex hands-on engineering activities demonstrated their potential to elicit noticeable differences in the spatial reasoning between the junior students and the senior students. Spatial inference making and abstractions improved with developmental age. Gender in a group setting emerged to be a variable that impacted on the organisation of individual sub-tasks within a challenge and the communication throughout the activity. This will be explored in greater detail by the main study, in particular, the observation of girls taking a central role in allocating tasks and driving the group’s decision-making process, in contrast to girls taking a ‘back-seat’ role when in high school.

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Technical or not? Investigating the self-image of girls aged 9 to 12 when participating in primary technology education

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Abstract

Variance in interest and engagement by gender is a complex and long-standing research agenda in the field of technology education. Studies report that girls are more reluctant to participate in technology education, less interested in the subject and more negative towards technology than boys. It is argued that specific attitudes and roles hinder girls from engaging in technology education because technology is presented as a predominantly male domain, which fuels ideas about what technological agency is as well as whose interest in technology and what kind of technology are regarded as legitimate. There is, however, the potential to improve female engagement if we can gain knowledge about what girls do during lessons and how they think about themselves when learning technology. Therefore, the aim of this study is to examine the self-image of girls aged 9 to 12 when participating in primary technology education, by using Harding's (1986) three gender levels: the symbolic, the structural and the individual. The methods used for this study were participant observations during technology classes followed by a focus group interview. From the perspective of Harding's three levels of gender, the analysis of the observations and the focus group interview reveals that girls confirm the prevailing male norms and conceptions that are linked to what technology is and what it means "to be technical", despite the fact that the teacher introduces gender-neutral activities. However, there is an ambiguity in our findings because the girls also resist the self-image of not being technical, especially when they work together and have ownership of their work with and learning about technology.

Key Words

Primary education, technology education, girls' self-image, gender, focus group interview, observations

Introduction

Girls' interest and engagement in secondary technology education have been explored to a certain degree. However, there is still a lack of research regarding girls and technology education in the early years of school (Kim, Sinatra & Seyranian, 2018). Previous studies – both the few carried out in primary schools and the majority carried out in secondary school – primarily concentrate on the differences between girls' and boys' engagement in technology education. Hussénus, Andersson, Gullberg and Scantlebury (2013) argue, however, that too many studies are restricted to comparing female and male students on variables such as students' achievement and attitudes. Other previous research (e.g. Kim, Sinatra & Seyranian, 2018; Turja, Endepohls-Ulpe, & Chatoney, 2009) suggests that while males are portrayed as being more interested in technology than females, societal factors such as upbringing,

education and the labour market may discourage girls' interest in and engagement with technology. Cheryan, Master, and Meltzoff (2015) point to how the construction of an identity as not being technical can manifest itself in and affect girls. This demands a new way of studying girls' relationships with technology, particularly in relation to education in which girls' interest and engagement are formed from an early age (e.g. Sultan et al., 2019). Therefore, in this study we focus on girls only, to gather clues and gain knowledge about their relationships with technology apart from boys, to the extent that this is possible.

Technology education is a mandatory subject for all Swedish pupils aged 7-16. In Sweden, specialised technology teachers teach younger children since it has been a mandatory subject since 2011 in current teacher education programmes for teachers teaching 7- to 9-year olds (school years 1-3) and an optional subject for teachers teaching pupils aged 10-12 (school years 4-6). 44.8% of all Swedish teachers in school years 1-3 and 48.3% of all teachers in school years 4-6 are qualified to teach technology education (Swedish National Agency for Education, 2020). According to the technology education curriculum, teaching should promote pupils' development of an interest in technology and their ability to take on challenges in an innovative way. Another purpose is for pupils to develop technological expertise and a technological awareness, to be able to navigate in a technological world. These purposes are the same for both sexes. The curriculum is written in such a way that it covers both technology that is culturally regarded as masculine technology and technology that is considered feminine. The Swedish National Agency for Education encourages activities to be gender neutral, thus moving away from what can be seen as gendered views of technology. The national school system therefore increasingly strives for gender equality and the inclusion of both girls and boys in technology education (e.g. Swedish National Agency for Education, 2018). For this reason, we have chosen not to discuss the idea of masculine and feminine technology further, but we instead describe what kinds of activities the pupils engage in.

In this study, we have chosen to use Ihde's (1993) three dimensions of technology: technology must have a concrete component, enter some set of praxes, and have a relationship with humans. This definition presents a responsive spectrum of human-technology relations, which can be seen as useful when studying gender issues. We define being technical as being knowledgeable or skilled with technology, in some set of praxes; design, construction or use.

Gender theory, technology education and the social construction of (not) being technical

When comparing genders, one gender will often be considered the "normal", and the other not (Cheryan, Ziegler, Montoya & Jiang, 2017). In this sense, boys are often seen as the norm for engagement and interest in technology education. In earlier research, this stereotype is linked with traits such as being handy, objective, rational, and non-emotional (Brickhouse, 2001; Smith & Hung, 2008; Emerson & Murphy, 2014). Given that stereotypes in the field of STEM (science, technology, engineering and mathematics) education tend to be male (Berg & Lie, 1995; Cheryan et al., 2015), female students are less likely to define themselves as being technical. In these settings, girls are more likely to disengage and adopt a self-image of not being technical (Kim, Sinatra & Seyranian, 2018). Labelling oneself as technical or untechnical is

related to social factors. Cheryan, Master, and Meltzoff (2015) suggest that the social environment and feelings of belonging may play significant roles in nurturing or hampering a

STEM identity. This points to the importance of social acceptance or having the community of technology education recognise the individual as a group member who fits in. When technology is constructed as a male domain and comprising male attributes, such as logic and technical knowledge, this tends to produce negative self-images amongst girls (Sanders, 2005). Girls also tend to encounter the technology content taught in school less often, thereby acquiring fewer skills and less knowledge about technology (Klapwijk & Rommes, 2009), which may exacerbate disengagement and the feeling of not being technical. On the other hand, teachers play a key role in dismantling such gendered practices and renewing the image of technology education, because they are well placed to induce changes in pupils' perceptions and identities (Murphy 2007). Previous studies show, for example, that girls are less concerned with negative stereotypes when they have a female teacher (e.g. Master et al., 2014).

Inspired by gender theory, we use Harding (1986) as our starting point and refer to gender issues on three levels, the *symbolic*, the *structural* and the *individual*, because these levels of the gender system are seen as "a pivotal way in which humans identify themselves as persons" (p. 18). Harding (1986) defines gender as an ordering principle by which every society is organised. In our analysis, the symbolic level concerns cultural norms, conceptions and linguistic expressions/dichotomies of what gender and technology are and what it means to be technical. The structural level regards gender in relation to the organisation of teaching; and the individual level involves a girl's (or a boy's) self-image or view of their identity in relation to technology and technology education.

The aim of this study is to examine the self-image of girls aged 9 to 12 when participating in primary technology education, by using Harding's (1986) three gender levels: the symbolic, the structural and the individual.

Methodology and Methods

To understand the complexity of gendered classroom situations we used Harding's (1986) gender levels as our methodological framework. The different levels should not be considered as separate entities, as they constantly interact with each other, but they are useful as analytical tools and for understanding the gender structures. The different levels applied to our view of girls' self-image can be seen in Figure 1.

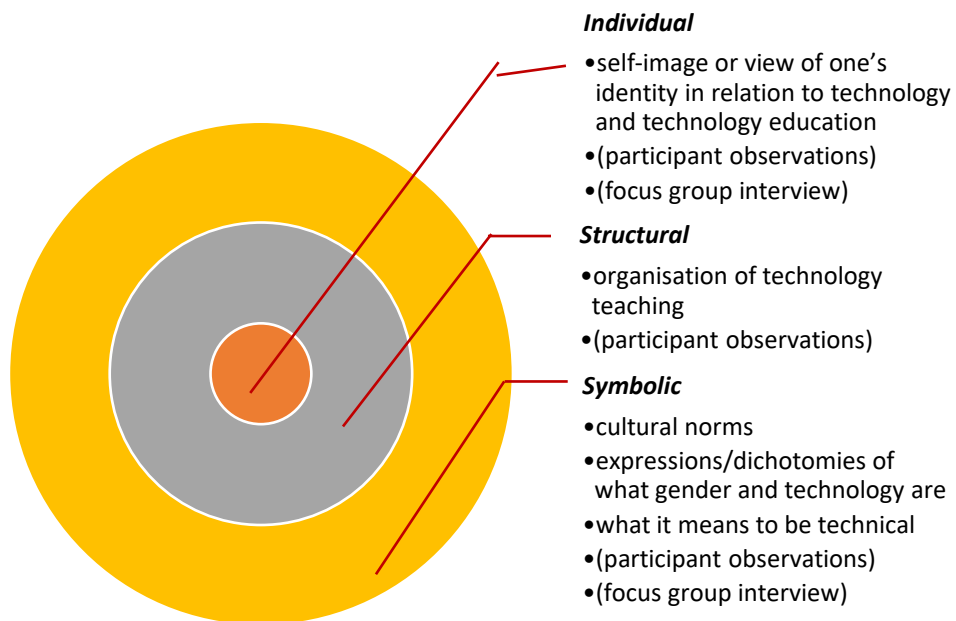


Figure 1. Visual model of Harding's (1986) three gender levels, the symbolic, the structural and the individual, in relation to our methodological approach. Methods used for each specific level in brackets.

Data collection was carried out through participant observations and a focus group interview, i.e. ethnographic methods were used. Conducting observations is helpful in order to understand the participants' world by actively engaging in activities in which participants are typically involved (Kawulich, 2012). The initial purpose of the observations was to develop a narrative (Bryman, 2016) of girls and technology during technology classes. We also used the method as a vehicle specifically to explore the individual, structural and symbolic levels by studying how the self-image of girls was expressed. The observations spanned a technology course of two weeks, involving one Swedish compulsory school and three different classes with pupils aged nine to twelve, during six lessons and a total of fourteen hours. The school is situated in an urban area with pupils representing diverse socio-economic backgrounds. The focus group interview lasted for one hour on one occasion, involving five girls who were observed during the technology lessons. There were two workspaces in the same classroom, divided by a wall, which consisted mostly of windows. One space was intended for woodwork and metalwork, and one was intended for textile work.

To obtain access to the field, an inquiry was sent out via a social media platform. One qualified and experienced technology education teacher responded and gave us access to a classroom and pupils. The teacher acted as a gatekeeper and helped us determine the best time to perform the study, and established a relaxed environment for the research process. The teacher was also an important discussant when trying to make sense of the initially collected data. Furthermore, the teacher's knowledge about the classroom setting and how best to obtain consent from the participants' parents, proved valuable for the study.

The observations were carried out by the first author and were based on knowledge gained from a previous study (Sultan et al., 2019) concerning what might be significant regarding girls and technology. The starting point for the observations – and relating to the structural level – was to document as much as possible about the physical setting, the context, the participants' gender, and their activities, following guidelines for doing observations by Kawulich (2012) and Merriam (1998). The first author focused only on the girls, as their interactions with each other were considered to be of particular importance. Data from the observations was collected by using field notes. There were no checklists or coding schemes to follow during the observations. The first author observed and took notes about conversations between the girls, and between the girls and the teacher, and took notes about which tools the girls used during class and how they expressed themselves in relation to technology. Thus, the field notes consisted of descriptions of the activities, quotations from conversations and the first author's own reflections during the activities. The observations were documented in a narrative style and, using qualitative content analysis, the data was analysed in a hermeneutic tradition and was thus organised and categorised after repeated reading (e.g. Elo & Kyngäs, 2008).

A focus group involves a group of people who discuss a given topic during a limited period of time (Morgan, 1996). As far as possible, the group interaction should resemble natural conversation focused on a specific topic or theme, hence the name 'focus' groups (Smith, 1995). The topic is usually introduced by a moderator and can be initiated by some form of stimulus material, e.g. recounting earlier observations or using visual media. The group members then discuss the topic or theme as freely as possible without much intervention from the moderator (Krueger & Casey, 2000). Focus group interviews allow researchers to gain a deeper understanding of certain events or phenomena observed during the observations. In the present study, the focus group interview was also used as a method to understand the individual and symbolic gender levels.

The hour-long focus group session led by the first author, FA was conducted with five girls, aged 9-12. The girls volunteered to participate and obtained their legal guardians' consent. At the beginning of the session, it was explained that we were interested in what they thought about issues relating to technology education. Extracts from conversations noted in the observations were presented as discussion material at the beginning of the focus group session. A semi-structured interview guide was used. The topics for the session reflected in the conversation extracts included themes such as 'confidence', 'being a girl', 'tools' and 'design'. The session began with a less sensitive topic, in this case how their school day had been, and continued with topics relating to 'girls and technology'. During the hour-long discussion, the interviewer directed and encouraged the discussion, introducing new topics when necessary and appropriate. The responses can partly be seen as the collaborative product of two contributors, the interviewee and the interviewer.

The analysis of the field notes from the observations and the transcripts from the focus group interview was performed in steps, roughly following Elo and Kyngäs' (2008) three main phases, preparation, organising and reporting, and related to the three levels of gender (Harding, 1986). The first step was an "open" reading of the field notes and transcripts to obtain an overall idea of their content. Each activity and conversation was labelled with a descriptive rubric to characterise its central meanings, and to facilitate the next step of the analysis. In the second step, units of meaning/codes were identified with reference to what was observed and

heard concerning girls' self-image in technology education, at the structural, symbolic and individual gender levels. A code consisted of one or more sentences of a narrative from the field notes and transcripts. In the third step, the codes were condensed and merged into categories, and were thereafter re-evaluated in order to avoid overlap. The codes were then related to the three gender levels (see Analysis). In the fourth step, an interpretation of the underlying meaning of the data in relation to the methodological framework and previous research was made – see Discussion (cf. Elo & Kyngäs, 2008).

Ethical considerations and validity of the study

The ethical principles for research were followed by informing the participants about the purpose of the observations and the focus group interviews, and about their right to consent and to discontinue their participation should they wish to do so. Consent was obtained from the participating pupils and their legal guardians. The participants were also informed about their participation being anonymous, and that the data would not be used for anything other than research purposes (Swedish Research Council, 2020).

Concerning the focus group interview, the interviewees/pupils felt comfortable in that they had met the interviewer before. This allowed the girls to feel relaxed. The teacher was involved in discussions about the design of the focus groups, so at the session the focus group members were informed that they could discontinue their participation in the group at any time. The girls who had chosen to take part in the focus group interview could also choose whether to participate actively. One of participants chose to say very little during part of the discussions. Smithson (2000) discusses the problem of dominant voices in focus groups, and the fact that some group members may remain silent. The choice of remaining silent can make the focus group method less intrusive, in comparison with a traditional interview. It allows the interviewee to avoid talking about individual issues that they may find sensitive.

This study is qualitative; the analysis concerns the data of this study and no generalisation should be drawn from it. Participant observations have the advantage of observing relatively rare or unusual behaviours that might have been missed with other deliberate, sampling methods (Emerson, Fretz, & Shaw, 2001). It might be a problem, however, if the researcher expects to see events that are not there and unconsciously creates those events. In this study, we therefore tried to be as open-minded and explorative as possible at all stages - from observation in the classroom to the interview. The research aim and methods reflect this openness.

Results

Observations

During the observations, the girls' conversations were documented. No data was collected on working skills or level of knowledge other than what emerged through the girls' own expressions. The included conversations are highlights from the field notes, and should be read as excerpts from classroom conversations that illuminate aspects of the self-image of 9- to 12-year-old girls in a Swedish technology classroom. Descriptions of activities, as they played out as conversations, and doing technology are marked with [DESCRIPTION OF ACTIVITY].

Reflections on the meaning, and FA's descriptive field notes about the activities and events surrounding the activity, are marked with [REFLECTIONS].

Transcription notations are based on Bailey (2008):

(.)	pause of less than a second
[]	encloses overlapping turns
**	encloses speech in a laughing voice
[]	encloses transcriber's comments (E.g. on non-verbal communication, tone of voice, etc.)

Activity 1: Girls' empowerment together – Girls aged 9 and 10 (years 3-4) (one lesson)

[DESCRIPTION OF ACTIVITY]

In the classroom, the pupils gathered around the interactive board and they were shown YouTube videos about different robots - from industrial robots to more futuristic ones. This was the introduction to a theme about fantasy robots. The teacher chose fantasy robots because it could lead to the pupils designing non-gendered technology – “robots are robots and can do whatever” – and because it might help the pupils when practising designing innovative, functional, and appealing products that are fit for purpose. After the videos, the pupils sat in their workspaces in groups of three or four. The pupils chose where they wanted to sit and who they wanted to work with. The eight girls in the class were divided into smaller mixed-gender group constellations, except for one group of four, which ended up being only girls. This group would turn out to be the most verbal one in the forthcoming group discussions. When the groups had been arranged, they were instructed to first think alone, inspired by the videos they had just been shown, and then to agree on what kind of robot they would like to construct a model of. The pupils were instructed to think individually about what kind of robot they would like to have, and the group must then reach a consensus about what capabilities and functions the group's robot should have. The pupils should use notebooks and sketch the robot they would like to have, write down what its function is, and finish by giving the robot a name. The teacher told the pupils to search on Google for drawings of robots, and then they should draw all the ideas that they could come up with. The pupils googled and discussed. The group with only girls discussed intensely about the kind of materials they wanted to use in their model and the kind of functions they wanted their robot to have.

[REFLECTIONS]

The girls in the mixed groups did not display the same intensity among the participants in the discussions as the girls in the all-girl group, so their roles were more confirming and agreeing with the rest of the group. In one mixed-gender group, however, one girl led her group discussions, taking on a leadership role and challenged the group's ideas. This girl suggested an angry bull with glowing eyes as the group's robot model. The group with only girls wanted the robot to do household chores, such as making the bed, doing the dishes, etc.

Activity 2: Girls reinforcing stereotypical notions regarding technology – Girls aged 11 (year 5) (two lessons)

[DESCRIPTION OF ACTIVITY]

This lesson was a mixed-subject session, in which the art teacher and the technology teacher shared a multidisciplinary project. The theme was space. The assignment that the pupils were asked to do was to create space dioramas. The technology part of the theme involved the use

of one or more simple machines to move the planets, the sun or spaceships within the dioramas. Possible solutions using simple machines could be to use a wheel and an axis to spin the sun, or a pulley to make a spaceship lift off from its home planet. The purpose of this lesson content was for the pupils to learn about simple machines and to apply their functions in new contexts. The assignment covered all aspects of creating a diorama – design, assembly, painting, creating planets and spaceships, etc. The pupils did not get to choose who they wanted to work with, and they were divided into mixed-gender groups with 4-5 pupils in every group. The pupils gave the impression of knowing what was expected of them in this assignment. In the group located in the paint room, a smaller room connected to the main area, the following conversation took place:

1. Girl 1: I don't like technology. [comment made to nobody in particular]
2. Girl 2 to Girl 3: One will instruct and the other will sketch what needs to be sawn. (.) OK?
3. Girl 3: If we do Saturn (.) we need to do the rings also.
[They produced their sketch and walked over to the jigsaw, to ask the boys for help with the saw.]

[REFLECTIONS]

The girls mostly asked each other for help when they were stuck. Glue guns were the specific tool of choice for the girls. Even when other tools could make the work easier, they chose to use the glue gun. When it came to decorating the dioramas, the girls took the lead and painted what they wanted, even taking a dominant position.

Activity 3: Girls' low self-efficacy concerning technology education – Girls aged 12 (year 6) (three lessons)

[DESCRIPTION OF ACTIVITY]

In the following lessons, the assignment was to build models of the different parts of a playground; a fair, swings and carousels. The class was mixed gender. The assignment was created in a way that allowed the pupils to be creative and follow their own ideas, while also having to use the skills they are expected to have in the subject in school year six. The teacher expected this assignment to engage both the sexes as the playground was considered a place of non-gendered technology. The pupils chose who they wanted to work with and where to sit whilst working on the assignment. There was a clear division between the sexes. Girls chose to work only with girls. Girls and boys engaged in small talk from time to time, but they worked separately.

Girl 1: [Walking around the room.] I'm so bad at this. [tired voice]

[REFLECTIONS]

The comment comes from nowhere while the girl is moving from one point to another in the room. Addressing no one.

[DESCRIPTION OF ACTIVITY]

All the girls except for three went to the paint room, as mentioned earlier. The teacher went after them to ask what they were working on, and commented that the girls should focus on the assignment instead of engaging in small talk. The girls split up and went back into the woodwork and metalwork area. Two of the girls sat down by the computer. They were creating

a spinning chocolate wheel and wanted to insert, create and print a Word document of a table consisting of columns and rows with names of colours to put on their chocolate wheel. The table was the first step in the process of constructing the chocolate wheel:

1. Girl 2 to girl 3: I'm no good at this. (.) We must do it another way to be able to paint [it later]. It has to be nice in terms of colours.
2. [Girl 3 tried to add a line to the document.]
3. Girl 2 to passing boy: Can you help us [with the computer]?
4. Boy: No, I don't know how it works.
5. Girl 2: But (.) you are good at computers.
6. Girl 2 to girl 3: If we insert a table, (.) one here, and add one here (.) then it might work. (.) Yes.
7. Girl 3: Yes.
8. Girl 2: Yes.
9. Teacher: Hey girls. Everything OK? (.) [looking at the computer screen] Are you making a table? You can decide how many rows and columns you want straight away. (.) You don't have to make them yourselves.
10. [The teacher left to help their classmates.]
11. [The girls continued working on the computer.]
12. Girl 2: I'm not good at this.
13. Girl 3: I don't get it.
14. [The girls turned to the same boy as above]: How do you spell lavender?
15. Boy: I don't know. I don't even know what that is.

[REFLECTIONS] The girls continued working at the computer, choosing the colours they wanted to use in the table embedded in their Word document, and making the table look nice. They were meticulous about the spelling of every word. During a period of 20 minutes sitting by the computer, they said eleven times that they do not know, that they do not understand or that they are not able to work with the computer.

[DESCRIPTION OF ACTIVITY] Two girls worked on their model for the playground. They had chosen what they wanted to construct, produced the sketch and agreed on a design, and were now in the process of working on the material for their build:

1. Girl 4: [asks teacher] Can girl 5 use this piece of wood and saw it?
2. Teacher: Yes, (.) no. (.) I'll help her. Be careful [to girl 5].
3. [Girl 5 used the jigsaw by herself, supervised by the teacher.]
4. Girl 5 to teacher: Can I drill a hole?
5. [Girl 5 asked a boy for help/]
6. [Girl 5 went to the pillar drill with two boys.]

[REFLECTIONS]

The teacher did not have a chance to answer before girl 5 asked a boy in the class for help with the drill.

[DESCRIPTION OF ACTIVITY]

Three out of four groups of girls preferred to work in the textile work section of the room instead of the woodwork and metalwork area, mainly sitting by the same table gluing their models throughout the whole lesson (60-80 minutes). The groups had different playground models they were constructing, but they all chose to integrate fabric into their models: pink, lilac, blue and white coloured fabric, or “pretty fabric”, as one of the girls explained.

[REFLECTIONS]

The chosen colours were design choices with no practical function, with the exception of one group, which made swings and wanted them to be comfortable for the user. Instead of using a variety of tools, the girls used glue guns to construct their models and combine different parts of the designs. They chose to do so even though they expressed that some tasks would be easier to solve and the models could be made more stable with other tools.

Focus group interview

The following data from the focus group interview was transcribed from audio recordings of the focus group session. It was conducted with voluntary interviewees and represented girls from all studied age groups. The focus group interview was conducted and led by the first author. Just before the first and second examples, FA read some of the transcript of *Activity 3*, and commented, for example, “I saw you spending a lot of time in the painting room and that you chose to sit in the textile area. Are you there often...?”

Conversation 1: Girls’ empowerment hindered by boys – Participants one to five (P1 & P2 engaging), First Author (FA)

- 1 P1 Sometimes the boys are just too much (.) I mean they are nice but if I am having trouble (.) and (.) I’m not allowed to do try (.) stuff (.)
- 2 FA Mmm.
- 3 P1 You know, solve it (.) it’s like: I don’t know (.) it’s like you have to go to the side and try it (.) like.
- 4 FA Mmm.
- 5 P2 If you are a girl [].
- 6 FA Mmm [].
- 7 P1 I don’t want them to tell me what to do

[REFLECTION] As can be seen, P1 first takes an impersonal construction in that she talks about ‘boys’, but then she starts talking about ‘I’, signalling that she is putting herself into the experience and sharing her lived knowledge. P2 joins in whilst the others, P3-P5, stay silent.

Conversation 2: Girls’ empowerment with stereotypical materials – Participants one to five (P1, P2, P3, P4, P5), First Author (FA)

- 1 FA You said something about materials and tools (.) that it is important.
- 2 P1 Yeah (.) it’s easier (.) you know.
- 3 FA Mmm.
- 4 P1 (.) you get like: should I use this ugly piece of wood or this sparkly textile (points a sequined textile) [I think anyway].
- 5 P2 [Yeah] it’s not (.) like great materials.

- 6 P3 No.
 7 P4 I know you make your own (.) but.
 8 P2 It's just not girly.
 9 P4 Yeah (.) mmm.
 10 P1 And it's always messy. **
 11 P4 [laugh] (.) we should clean it more.
 12 P1 And the noise (.) it's more fun in the textile area (.) we can talk and work.
 13 FA Mmm.
 14 P5 And we know how all the things work in there.
 15 All (laughter)
 16 FA it's easier (.) to ask (.) it's like easier to ask for help if you get stuck.
 17 P1 Yeah: [I think so too.]
 18 P2 Mmm.

[REFLECTION] Here, the interviewees bring forth shared experiences that make it easy to co-construct scenarios. When P1 talks about ugly materials (turn 4), P2 exemplifies by creating a setting (turns 8–10). In this example, it can also be seen how the FA formulates a leading question (turn 1). The co-constructed scenario is a collaborative product, involving participants' co-produced experience, knowledge and thoughts. A key feature of the focus group method is the interaction among participants and creation of articulated descriptions.

In Conversation 3, one of the areas that evoked strong opinions was the question of what technology is.

Conversation 3: Girls' conceptions of technology – Participants one to five (P1, P2, P3, P4, P5), First Author (FA)

- 1 P1 It's everything (.) robots, programming, space stuff (.) I'm not the best at it (pause) but it's fun. (pause) I'm good at sloyd. [Educational sloyd is a Swedish school subject which can be described as a variant of craft education.]
 2 FA Mmm.
 3 P1 [and our teacher is great.]
 4 P5 [I like using my imagination to make things (.) Like a robot.]
 5 FA Is the drill you use also technology?
 6 P3 No (.) it's more something you use to make things.
 7 P1 No but (.) listen ((annoyed)) the tools are tools.
 8 FA Is the glue gun technology then?
 9 P3 Mmm [but that isn't what I mean but no (.) yes (.) no. You use it.]
 10 P1 Everyone does that today.
 11 FA What?
 12 P1 Use a glue gun.
 13 P3 [Yeah.]
 14 P5 [Yes.]
 15 P3 Not everything is technology (.) some things make technology.

[REFLECTION] P1 tells the group what technology is and how she feels about it and her teacher. P5 reflects on her statement by talking about what she likes. P1 protests, with a 'no but': 'tools are tools' in reply to FA's question about the drill as technology (turn 5). P1, P3, and P5

collaboratively state that a glue gun is not technology since (turns 9, 13, 14 and 15) ‘everyone does that today’ (turn 10).

In Conversation 4 we focused on being technical. Do they, the interviewees, see themselves as technical?

Conversation 4: Girls supporting each other – Participants one to five (P1, P2, P3, P4, P5), First Author (FA)

- 1 P5 I can't really say that I am technical.
- 2 P1 I think you are.
- 3 P3 Yeah me too.
- 4 P5 But I am not (.) Why?
- 5 P1 I just think you are.
- 6 P4 Yeah (.)
- 7 P1 You know.
- 8 P3 You help us (.) with things and stuff.
- 9 P1 I don't know (.) you just are (.) technical (laughs).
- 10 P5 (smile) I don't know (.) I like it (.) I'm just not that technical (.) I just do it (.) I don't ask for help much [pause].
- 11 P1 You are anyway.
- 12 P5 I suppose (laughs).
- 13 FA Yeah (.) it feels good.
- 14 P5 No [pause] yes [laughs].

[REFLECTION] The other interviewees support P5 in identifying her as being technical. Together, they co-construe her as a person who ‘help us (.) with things and stuff’ (turn 8). P5 expresses contentment for the support that she receives from her peers. In return, she does acknowledge being technical: ‘I suppose’ (turn 12).

Analysis

The symbolic gender in relation to technology

According to Harding (1986), the symbolic gender is so incorporated into our culture that it can be difficult to be aware of. It is expressed, for example, through language and through linguistic dichotomies. The analysis of the observations and the focus group interview shows that the girls largely confirm the prevailing norms and conceptions that are linked to what technology is and what it means “to be technical”. In the gender homogeneous groups with only girls, the girls also acted as confirmers of prevailing norms, while at the same time confirming and supporting each other as being technical. The dichotomies active–passive were also identifiable, as the girls seemed to assume that the boys were better at using technology (for example, the computer), and they asked for help even when the boys said they could not solve the problem either. By acting as “helpless”, the girls not only got the boys’ attention but also contributed to the creation of the image of “the technologically competent and handy man”. The symbolic aspect of gender was also confirmed by the girls when they discussed what chores they thought a robot should take care of. Making the bed, washing the dishes, etc., are all chores that are linked to the female gender. Likewise, the girls preferred to use tools (glue guns) that can be considered on a symbolic level to be more “feminine” compared to other

tools such as saws and drills, despite the fact that the girls were aware that the other tools would facilitate their construction work. They also chose to focus on materials and colours, and used descriptions like “ugly piece of wood”, “sparkly textile”, “great materials”, “pretty fabric” and “it’s not girly”. Through these descriptions, prevailing dichotomies can emerge and reinforce what is regarded as female and male in relation to technology. Taken together, the girls largely confirmed prevailing norms and conceptions.

However, despite this, we identified a duality. Although the girls confirmed prevailing norms, they simultaneously expressed a dissatisfaction. This dissatisfaction was expressed via statements to the effect that they were not given enough space by the boys to try things for themselves, and that they did not like it when the boys told them what to do. At the same time, they asked the boys for help, even when they had the opportunity to try to solve the problem themselves. This duality can be linked to the individual level of gender, i.e. the girls’ socially constructed identity in relation to technology and technology education.

The individual gender in relation to technology

How the individual gender was expressed by the girls in relation to technology and technology education can be linked to the girls’ view of what “technology” is and what “being technical” means. As mentioned in the description of the symbolic gender, the girls asked boys for help, indicating that they did not see themselves as technologically competent enough to solve problems themselves. This view was also confirmed by statements like “I’m not good at this”, “I don’t know how it works” and “I don’t get it”. One possible interpretation of the girls’ view of being technical is that it is closely linked to being able to use a certain technology without having to ask for help from someone else (preferably boys or men). However, at the same time, the girls expressed that they were not given the opportunity to use their technical ability; that they felt that the boys took up too much space and prevented them from “trying stuff”. However, here too, we identified a duality; in the observations, we noticed that the girls asked the boys for help to solve different technological problems.

Another aspect we noted in relation to gender was that the girls expressed how they were unsure about what technology is. They described technology as “everything”, but only gave examples of what it might be by mentioning robots, programming and “space stuff”. Moreover, they felt uncertain about whether or not tools could be regarded as technology. A drill was not technology since it is something “you use to do things”, but at the same time, they were not sure whether a glue gun was technology. This duality can be linked to the symbolic level of gender, that is, expressed through language and through dichotomies and the individual level connected to “being technical”.

The structural gender in relation to technology

Based on Harding’s (1986) description of the structural gender, we could see that the teacher was trying to influence the organisation of teaching so that it would not reinforce stereotypical notions. For example, the technology assignments the pupils were given can be considered to be gender neutral and the teacher supported both boys and girls equally. Similarly, the analysis of the interviews showed that the girls were aware of prevailing gender structures and they expressed that they were not satisfied with them. However, regarding the teaching groups, there was a clear division; the girls only worked with girls. Although girls and boys talked

occasionally, they worked individually and in mixed-gender groups, the boys took the lead. In relation to the structural gender, the girls preferred to use tools that could be considered more feminine coded (for example, the glue gun) compared to using saws and drills. They also chose to work in the textile work section of the room rather than in the woodwork and metalwork part. Moreover, by frequently expressing that they do not like technology and are not good at technology, and by asking the boys for help, the girls (possibly unconsciously) contributed to reinforcing stereotyped structural images linked to technology.

Discussion

The above analysis shows that the issue of girls' self-image when participating in primary technology education is complicated and sometimes contradictory. By using the methodological framework devised by Harding (1986), we were able to consider girls and gender in technology education on three different, interconnecting levels (cf. Rooke, 2013). On the level of symbolic gender, we identified a complex duality. On the one hand, the girls confirmed prevailing norms and traditional gender roles, and seemed to assume that boys were better at using and constructing technology by asking them for help. On the other hand, the girls simultaneously expressed their dissatisfaction with being set aside and being told what to do, and confirmed one another as being technical (cf. Hallström, Elvstrand & Hellberg, 2015).

The girls' own self-image or view of their identity in relation to technology and technology education is mirrored on the individual level, which shows that although the assignments were gender neutral and the teacher was supportive, the 11-year-old girls in particular adapted an image of not being technical, as discussed by Kim, Sinatra and Seyranian (2018). These girls frequently expressed that they do not like technology, or that they are not good at technology, in contrast to the boys who were seen by the girls as being technical – despite one of the boys protesting about being labelled as “good at computers” (cf. Virtanen et al., 2015). Based on Harding (1986), we suggest that the girls in this study tended to fulfil a negative technological self-image and chose to use artefacts, which may be an obstacle to their unbiased engagement in technology education (e.g. the glue gun). Even here, however, we identified a duality or ambiguity because we also noticed that the girls' view of being technical was closely linked to being able to use a certain technology without having to ask for help from someone else, i.e. from boys. In addition, as we have seen, the girls sometimes did just that (cf. Cheryan, Master, & Meltzoff, 2015).

The analysis of the observations at the structural level with regard to the organisation of teaching does not show the girls to have been subjected to negative stereotyping. Aspects identified as necessary for the creation and implementation of successful STEM education projects for girls include the ability of pupils to form collaborative groups and participate in solving problems that they identify as meaningful, relevant to them and open-ended (Billington et al., 2014; Denner & Werner, 2007), which the teacher in our study provided. However, regarding the teaching groups, there was a division in the sense that the girls only worked with girls, and even in the mixed-gender groups they worked separately and it was mainly the boys who took the initiative. In relation to the structural gender, the girls preferred to use tools that could be considered more feminine coded (for example, the glue gun) compared to using saws and drills (similar to a preschool context, see e.g. Hallström et al., 2015).

In terms of the implications of this study, Rooke (2013) points to a few key factors for gender-inclusive technology education, for example that it should provide a perspective valuing both technology process and product, and should rely on examples relating to both girls and boys. Another factor is working in small groups, without support from the teacher. Rooke (2013) concludes that “To create a gender-neutral environment for education, the tasks and the learning surroundings must allow the pupils to use different ways of solving the assignments. [...] By working contextually, you also get the opportunity to value technical solutions. Also, girls’ acquirments are gained by putting the task into an everyday perspective.” (p. 12.) Another important factor in order to maintain girls’ interest in technology education is that the teacher also chooses assignments that are gender neutral and do not separate technology into masculine or feminine attributes (Billington et al., 2014; Denner & Werner, 2007).

Finally, our results regarding the 11-year-old girls might align with earlier research claiming that girls often lose interest and confidence in technology from this age (e.g. Ardies, De Maeyer & Gijbels, 2015; Swedish Schools Inspectorate, 2014), but this needs to be explored further. By using the three levels of gender from Harding (1986), such a study could contribute to the understanding of girls’ interest in technology and technology education.

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Broadening the Horizons of Technology Education: Using Traditional Cultural Artefacts as Learning Tools in a Swedish Sámi School

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Abstract

The aim of this case study was to explore the nature of technology education in a Sámi school setting and to examine how knowledge about traditional cultural artefacts can contribute to broadening the horizons of technological literacy. The participants (teacher and pupils) in the study were all from the same Sámi primary school in Northern Sweden, and the activities connected to the artefacts took place with year 2 and 3 pupils. The method employed was participatory observation, and field notes, recorded conversations, photographs and children's drawings were analysed using a qualitative content analysis. The findings show that technology education in this school was connected to specific artefacts that are important in Sámi culture. Using these traditional cultural artefacts as a starting point, the pupils were given the opportunity to see that technology is more than modern high-tech; it is an age-old tradition of problem-solving, modification and adaptation to fulfil human needs. Technology education in this school was grounded in a holistic view of knowledge and was largely integrated with other school subjects. Myths and storytelling were frequently used to contextualise the technological content, and the historical aspect of technology was clear since connections between older and newer technological solutions were frequently made. The knowledge system embedded in the technology teaching can be described as collective and related to both artefacts and activities. Technological knowledge, activities and specific artefacts were not only attributed a practical value, they were also given a symbolic value, since a common knowledge base in technology contributes to strengthening the children's cultural identity. This study confirms that artefacts can play an important role in technology education and that an understanding of the relationship between technology and culture can be regarded as a critical part of technological literacy. A cultural context, in combination with a holistic perspective on learning, gives artefacts meaning and provides a context within which they are used. Including indigenous technological knowledge can thus not only prevent a marginalisation of indigenous knowledge, it can also provide opportunities to broaden pupils' perspectives of what technology is, how it evolves, and the driving forces behind technological change.

Keywords

Technology Education, Technological Literacy, Sámi School, Technology, Culture, Indigenous Technology

Introduction

Technological literacy – essentially the capability to understand and use technology (e.g., ITEA, 2007; Jenkins, 1997) – is an increasingly central goal of technology education worldwide. Definitions of technological literacy vary from comprehensive to vocational, but most definitions rely primarily on Western knowledge systems (Gumbo, 2018; Marshall, 2000; Williams, 2009). Hence, students in many countries perceive the content of technology education in a narrow sense as being mainly about modern, Western artefacts such as computers, tablets and TVs (Dakers, 2006; de Vries, 2005; Gumbo, 2017, 2018; Svenningsson, Hultén & Hallström, 2018).

However, since technology is a global phenomenon, it is important that knowledge about it includes technology from different cultural contexts and not merely technologies produced and used in limited parts of the world (Edgerton, 2011; Gumbo, 2015; Ihde, 1990). Narrow conceptions of technological literacy are misleading when it comes to the global magnitude of technological culture, and could potentially marginalise indigenous knowledge systems (e.g. Gumbo, 2012; van Wyk, 2002; Williams, 2009).

Indigenous knowledge can be described as “the complex set of activities, values, beliefs and practices that has evolved cumulatively over time and is active among communities and groups who are its practitioners” (Owuor, 2007, p. 23). Consequently, one difference between Western and indigenous technology is that the latter is often based on knowledge developed over many generations (Bondy, 2011; Gumbo, 2018). It is generally transmitted from one generation to the next through oral narratives, storytelling, music, symbols and art, as a way of maintaining societal continuity (Owuor, 2007).

The importance of including different cultural perspectives on technology is highlighted in research into technology education, where scholars suggest that indigenous technology and knowledge systems can contribute to broadening the horizons of technology education and technological literacy (e.g. Ankiewicz, 2016; Bondy, 2011; Gumbo, 2015, 2017, 2018; Lee, 2011; Marshall, 2000; Seemann, 2000, 2010; van Wyk, 2002). Other researchers argue that including indigenous knowledge and culture in education would be beneficial not only for indigenous students, but for all, since it could enhance understanding of indigenous cultures and alternative world views (e.g. Gumbo, 2015, 2018; Johansson, 2007; Lee, 2011; Svonni, 2015).

The Sámi are an indigenous people spread over four countries: Sweden, Norway, Finland and Russia. Altogether, there are about 100,000 Sámi people and the Sámi population in Sweden is approximately 20,000. In 1981, the Swedish Government established a Sámi School Board, with the mission to give Sámi children an education with a Sámi orientation and teaching in the Sámi language. Sámi schools have the formal power to implement Sámi culture, and today, there are five Sámi Schools in Northern Sweden (Johansson, 2007, 2009; Svonni, 2015). However, despite the fact that Sámi are the only indigenous people in Sweden (and the only indigenous people of the European Union), Sámi themes have been given limited space in the central content of the compulsory school national curriculum in Sweden (Svonni, 2015), to a lesser extent than indigenous knowledge in countries such as South Africa (Vandeleur, 2010).

The Sámi curriculum in Sweden is equal to the general compulsory school curriculum. However, the Sámi curriculum emphasises that Sámi pupils should be given the opportunity to become familiar with Sámi cultural heritage (Balto & Johansson, 2015; Swedish National Agency for Education, 2018). The Sámi knowledge system is holistic, place-bound and based on inherited wisdom and knowledge. It is also often linked to practical applications and skills (Keskitalo & Määttä, 2011; Keskitalo, Määttä & Uusiatutti, 2012; Svonni, 2015).

The aim of this case study was to explore the nature of technology education in a Sámi school setting and to examine how knowledge about traditional cultural artefacts can contribute to broadening the horizons of technological literacy. The purpose was to identify:

- Which specific artefacts play a central role in technology education in a Sámi school, and
- How these artefacts are implemented in technology education to convey technological knowledge.

Background

Keirl (2006) describes technological literacy as having three important dimensions: *the operational* (students learn to use and do the technology), *the cultural* (students contextualise their learning) and *the critical* (students learn about and how to be with technology). Hence, technology can be described as having both physical and intentional properties. The physical properties interact with other physical things in the world, whereas intentional properties relate to human beliefs, desires and purposes (de Vries, 2005; Kaplan, 2009; Kroes & Meijers, 2002). A technological artefact is thus a result of both physical and intentional conditions (Kroes & Meijer, 2002; Vermaas, Kroes, van de Poel, Franssen & Houkes, 2011), and can be described as having a function to extend human capabilities (Lawson, 2008, 2010). Artefacts play an important role in teaching and learning about technology. Exploring their composition, their materials, their design and their possible functions can support students' interest and knowledge in technology (de Vries, 2005; Frederik, Sonneveld & de Vries, 2011).

Since technology involves something that people have made or done, it also involves human values and is therefore always inherently situated within a culture and its values. Culture gives the artefacts meaning and provides the rituals within which they are used. Values are also closely connected to the objects and thus reflected in their form and function (Lee, 2011). The fact that technologies are linked with humans-in-culture implies that technologies have no 'essence' in themselves; they are only what they are in their use (Ihde, 2006).

However, *culture* is a complex concept. James (2015) defines it as "a social domain that emphasises the practices, discourses and material expressions, which, over time, express the continuities and discontinuities of social meaning of a life held in common" (p. 53). James (2015) explains 'culture' as being connected to *how* and *why* we do things. 'How' is about our material practice, while 'why' is connected to the meanings.

Since the cultural aspect is central in this study, Ihde's (1993) broad definition of technology is used when analysing the data, i.e. that technology has some concrete components, that humans use these components in praxes, and that there is "a *relation* between the

technologies and the humans who use, design, make, or modify the technologies in question” (p. 47). According to Ihde (1990, 1993), technologies cannot be understood as an independent power since they are always interwoven with culture. Since technologies provide a framework for human actions, they have a certain influence on those actions.

A problem highlighted in previous research is that when a teacher presents a limited view of technology, there is a risk that students will adopt a narrow view of what ‘technology’ is, and of the school subject technology (e.g. Mawson, 2010). Gumbo (2017) defines technological artefacts as expressions of culture, and argues for not restricting teaching technology to a Western perspective. Gumbo notes that multiple culture perspectives can facilitate and broaden students’ understanding of technology and its connections to culture. A limited understanding of indigenous technological artefacts easily leads to ‘museumisation’ and shallow conceptions of artefacts (Gumbo, 2015, 2017). Lee (2011) agrees with Gumbo when suggesting that traditional cultural examples can support contemporary technological concepts and create opportunities for students to develop a broader understanding of technology. Knowledge of indigenous cultures can support the contemplation of technological developments, not least from a sustainability perspective (Lee, 2011; Utsi, 2007).

There is also research indicating that pupils are often not given the opportunity to analyse technology in a meaningful context. Too strong a focus on using and making artefacts can lead to the connections between artefacts and humans, and the artefacts’ implications in a societal/cultural context, being disregarded (Mawson, 2010; Siu & Lam, 2005; Turja, Endepohls-Ulpe & Chatoney, 2009).

Based on this background description, this study focuses on using traditional cultural artefacts as tools in technology education in a Swedish Sámi school.

Methodology

Qualitative research was conducted in the form of a case study, since the aim was to explore technology activities in a specific context including several participants (Fraenkel, Wallen & Hyun, 2019). The method employed was participatory observation. Marshall and Rossman (2011) define observation as “the systematic noting and recording of events, behaviours, and artefacts (objects) in the social setting” (p. 139). Participatory observation facilitates the researcher’s involvement in a variety of activities over an extended period and therefore provides a deeper understanding of the studied field. It is a method for understanding what is happening in a specific context, and the experience is connected to a specific place and time (DeWalt & DeWalt, 2002). The observations can be of different degrees: non-participation, passive participation, active participation, and full participation (Spradley, 1980). Participant observation gave the researcher a personal experience of the studied phenomenon.

This case study was conducted at a Sámi compulsory school in Northern Sweden. The school provides education from preschool class to year 6 (ages 6 to 12). There is also a Sámi preschool at the same premises.

The study followed the Swedish Research Council’s (2017) ethical considerations and guidelines, and the participating pupils had their guardians’ consent to take part in the study.

The data was collected over a period of two years, during five visits to the school. Each visit lasted four to six days.

The data consists of observations of daily activities with pupils, as well as teacher meetings and other events during the school day. The participating observations varied depending on the activity, and they were recorded via field notes, photographs, audio-recorded interviews/conversations and children's drawings. The field notes were written in narrative form.

In the classrooms, both Swedish and Sámi were spoken, as the pupils' knowledge of the Sámi language varied. However, when teaching was carried out in Sámi, the teacher translated and explained to the author afterwards.

The material was analysed using a qualitative content analysis inspired by Erlingsson & Brysiewicz (2017), i.e., a repeated and interpretive process in which the meaning of a part can only be understood when related to the context. Based on the study's aim and research questions, the objective was to identify recurring themes in the empirical material. The first step was familiarisation with the data, which meant reading and re-reading field notes and the transcriptions of recorded interviews/conversations. The text was condensed into smaller parts and categorised by content. According to Erlingsson & Brysiewicz (2017), a category manifests obvious and visible content in the data and is characterised by answering the questions *who*, *when*, *where*, or *what*. Finally, similar categories were grouped into themes. A theme can be described as expressing underlying (interpretive) meanings, answering questions like *how*, *why*, or *in what way* (Erlingsson & Brysiewicz, 2017). In this study, the process of identifying themes relates to Keirl's (2006) dimensions of technological literacy: operational (how), cultural (why) and critical (in what way).

Findings

The initial analysis of the material revealed specific traditional cultural artefacts that provided starting points for various technology-related activities, including:

- A temporary Sámi dwelling, *lávvu*
- Sámi winter footwear, *nuvttagat*
- Sámi shaman drum, *goavddis*

The following description of the activities is based on the questions Erlingsson & Brysiewicz (2017) suggest relate to the step in the analysis process termed *categorisation*: *Who* are the participants in the activity? *When* is the activity taking place? *Where* is the activity taking place? *What* kind of technology activity? (Descriptive.)

The activities connected to these artefacts took place in the same class, years 2 and 3 (pupils aged 8-9). In the following descriptions of the technology activities, field note extracts and photographs have been selected to illustrate what was seen as significant for how the artefacts were implemented in the technology teaching. The quotations are representative illustrations of discussions that frequently arose during the activities. The quotations have been translated into English by the author.

Technology Project 1: A temporary Sámi dwelling (*lávvu*)

The teacher informs the researcher that there are different types of traditional Sámi dwellings. The *lávvu* is a mobile, lightweight dwelling, consisting of poles and tent fabric. The *lávvu* is used as a temporary shelter and is similar in design to the Native American tipi, but is more stable to cope with strong winds. The foundation consists of three forked poles that form a tripod – the basis of all Sámi building constructions, according to the teacher. Each member of the family and each item has its own specific place in the dwelling. In the middle is a fireplace (*árran*). Opposite the door, on the other side of the fireplace, is the kitchen – a sacred place to which a specific goddess is connected, and where the most valued items are stored. The fireplace is surrounded by larger stones and the floor of the *lávvu* is covered with birch rice with a reindeer or elk skin on top. The birch rice is replaced weekly.

The teacher explains to the researcher that life in a *lávvu* largely involves: “Hand me [something]”, “send me [this/that]”. She summarises her description of the *lávvu* by explaining: “The *lávvu* is our caravan. It is portable.”



Figure 1. Models of the *lávvu*.

The *lávvu* project starts with a visit to the Sámi museum, followed by a lesson in one of the Sámi dwellings in the school yard. This includes teaching about the unwritten rules connected to being in a *lávvu*.

The pupils draw pictures of a *lávvu* based on what they learned about its different parts and spaces, the name of which are written in Sámi.

The next step in the project is to construct a model of the *lávvu*. This begins with a lesson in the forest.

1. The lesson is about different kinds of trees, and the pupils were asked to cut willow branches using secateurs. The branches were then cut into three forks using knives. The pupils also scraped the branches and collected the bark. Back in the classroom, the bark was

put into boiling water and an experiment was conducting by putting a piece of paper in the decoction to see what happened. (The paper was dyed.)

- Each pupil received a wooden plate. Three holes were made with a hand drill and the three poles were fastened. Glue was used to stabilise the structure.
- The fireplace was created by gluing stones in a circle in the middle of the wooden plate. Pieces of birch twigs were also glued to the “floor” of the *lávvu* (Figures 2 and 3).



Figures 2 and 3. Construction of the fireplace (*árran*).

- The pupils made storage vessels using modelling clay made from flour, salt and water. Used tea lights were used to create a pot for cooking over the fire.
- The final step in the construction of the *lávvu* was to put canvas over the structure. This consisted of two halves which were laid from behind and forward towards the door opening. The door was made from a piece of cloth which was held in place by wooden slats and hung using string from one of the bars over the door opening (Figure 4).



Figure 4. The door.

The pupils discuss their *lávvu* models with the teacher and the researcher:

Teacher: "Where do you want to place your *lávvu*?"

Pupil: "Close to a brook, because then it is like in reality."

Teacher: "Is close to the reindeer round-up site, then?"

Pupil: "Yes."

The researcher and a group of pupils look at their *lávvu* models and the researcher asks them how a *lávvu* is constructed.

Pupil: "These are the ones you start with (points at the wooden poles) three big ones... this one is kept up like this... like a crutch (points at the forks). Then you take those smaller ones..."

Researcher: "Ah... the forks make it stable... and stick together..."

The researcher and the pupils discuss what the *lávvu* looks like inside.

Researcher: "Where do you sleep in the *lávvu*?"

Pupil 1: "At the sides." (demonstrates using the *lávvu* model)

Researcher: "And what do you bring into the *lávvu*?"

Pupil 2: "A sleeping bag."

Researcher: "[Do you bring] a sleeping mat?"

Pupil 2: "Well, you can also use a reindeer skin."

Researcher: "And here [on the *lávvu*'s floor], is it birch rice?"

Pupil 2: "Yes, so it doesn't get so wet."



Figure 5. Different stages of the *lávvu* model.

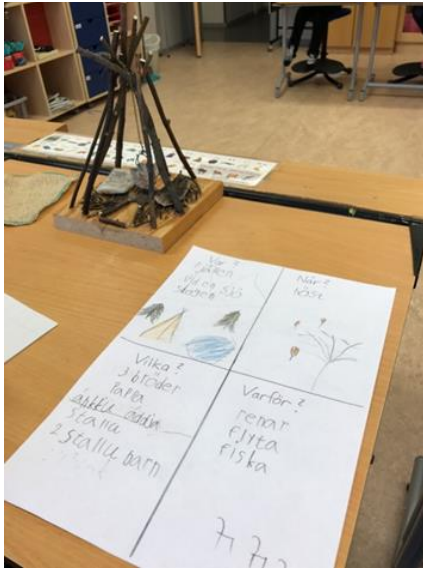


Figure 6. Preparing to write a story.

The pupils were also asked to write a story about the *lávvu*. They were given a sheet of paper divided into four fields with a question in each field: *Where? When? Who? Why?* The pupils filled in who lived in the *lávvu*, where the *lávvu* was situated, when the story took place and why the main characters were in the *lávvu* (Figure 6). The pupils then wrote their own stories. They are the main characters themselves in their stories.

Teacher: “What season is it? How did you get there [where the *lávvu* is placed]? By ski or by snowmobile? Who are you with... and what are you going to do there?”

Pupil 1: “We are going to be at the reindeer round-up site... to mark the calves... and to fish.”

Pupil 2: “We are going to hunt.”

Most of the children wrote that the characters are in the *lávvu* because they are going to hunt, fish or take care of their reindeer. Several of the children draw dogs or other animals like hares, and some draws bear tracks. *Stallo*, a common figure in Sámi mythology and folktales, was also present in one of the pupils' stories.

Technology Project 2: Sámi winter footwear – making threads from reindeer sinews

In the staff room, the teacher informs the researcher that the traditional Sámi winter shoes are made of hide from the legs of the reindeer. Since the hide is thicker in different places on the reindeer's legs, it is important that each piece is put in the right place. Many small pieces are put together. Underneath, the fur pieces are placed in two directions so the wearer does not slip (Figures 7 and 10). The toe hook was originally for putting on skis.

Teacher: “We [the Sámi] have almost invented the ski. It belongs to our history. It goes without saying that we should do work with skis and skiing [at school] ... We talked about getting those old skis, with just one strap... and [talk with the pupils about] why our shoes look like they do with this ‘beak’. It is a skiing bond... [It is important] that they [the children] understand why things are [constructed] as they are...”

According to the teacher, Sámi culture includes “a lot of things that are very old, but we still can and still do”, such as baking bread on a flat stone over a fire, traditional Sámi ice fishing methods, Sámi handicraft (*duodji*) and how to tie and use different knots.



Figure 7: A Sámi winter shoe

Narratives such as fairy tales and myths are often used in the teaching in this school, and the teacher introduces the activity to the pupils by reading aloud in Sámi from a Sámi picture book, *Silbamánnu*, “Silver Moon” (Horndal, 2016). The story is about a Sámi girl who is very good at spinning threads. One day, she is captured by *Stallo*, a well-known character in Sámi mythology. *Stallo* is a giant troll who eats people. However, the girl outwits *Stallo* by unravelling one of her threads, all the way to the place she is held captive. She is rescued and *Stallo* is killed. The book contains illustrations of artefacts with ancient histories: Sámi clothing, Sámi shoes, a wooden spindle, a wooden milk bowl, a walking stick and longbows. However, modern artefacts such as a quad bike, binoculars, a walkie-talkie and electric power lines are also depicted.

The teacher gathers the pupils in a circle on the floor. She has brought an old Sámi wooden spindle, like the one depicted in the book (Figure 8).



Figure 8: A Sámi wooden spindle.

The teacher shows the spindle to the pupils and uses its Sámi name. She has also brought a bag of sheep's wool, and takes a wad of wool and rolls it against her leg (Figure 9).



Figure 9: The teacher rolls the wool

Teacher: *“You soak it a little bit like this [with water] ... and put the threads over each other. Look, now it becomes a little bit longer! I can use these threads to knit a sweater ... But if I’m going to sew shoes... I need a strong thread.”*

The teacher shows a Sámi winter shoe made of reindeer hide (Figure 10). She has also brought an object that looks like a bunch of thick yellow threads.

Teacher: *“What is this? Banana peel?”*

Pupil 1: *“Sinews!”*

Teacher: *“Where are they from, the reindeer sinews? Where can you find them?”*

Pupil 2: *“Behind somewhere.”*

Teacher: *“Yes, they are on their legs, so they can move.”*

The teacher puts sinews on a wooden board and starts to process them with a rubber hammer (Figure 11).

Teacher: *“Look, now I have loose threads... When they are this small, I soak them... (she soaks the threads with some water from a cup), and then I spin them like this, against my leg.”*



Figure 10. A Sámi shoe made of hide.



Figure 11. The teacher works the reindeer sinews.

She puts several threads together and rolls them back and forth on her leg.

Teacher: “Now it’s finished. Look, how nice! There are 12 threads... I got these from my mother [the sinews].”

The teacher passes some sinews to the pupils. She repeats the Sámi word for “sinews”.

Pupil: “I have sewn with sinews at home.”

The teacher repeats what reindeer sinews are called in Sámi. The pupils are then divided into two groups. One group is going to make sinews threads and the other goes to the classroom next door to make yarn braids.

All pupils are given the chance to work the sinews with the rubber hammer and then twist the threads with help from the teacher. The challenge is to split the threads. The pupils explore the

structure of their threads. One of the pupils pulls the thread to see how strong it is and realises that it is very hard to break:

Pupil: *"You can use it as dental floss!"*

Teacher: *"Yes, if you don't have sinew threads, you can use dental floss [to sew the shoe]."*

Most of the pupils want to use the sinew threads as bracelets, and the teacher helps them tie the threads around their wrists.

In the afternoon, the class watches an old documentary (from 1923) about the lives of the Swedish Sámi people: "In the Land of the Mountain People". It is a black and white silent movie, and the teacher acts as narrator. While watching the film, the teacher points out things that can be linked to the activity with the sinews, for example a scene showing how tendons from reindeer are hanging on drying racks, and when women process sinews and then use them to sew. She also points out the Sámi shoes that people are wearing.

Teacher: *"Look, they used shoe hay instead of socks in the past."*

One of the pupils immediately responds to what the teacher says:

Pupil: *"I've seen that!"*

During the film, the teacher also refers to another technology activity they had previously carried out, the *lávvu* project. Examples of other technological solutions mentioned in the discussions between the teacher and pupils and between the pupils during the lessons include knives, fishing and hunting gear/methods, artefacts connected to traditional Sámi handicraft, fire-making methods, traditional food technology methods, snowmobiles, motorbikes, quad bikes and helicopters.

Another day, in the staff room, the teachers and the researcher discuss the importance of using stories in all teaching, including technology teaching. The teacher tells the researcher that when the pupils were in year 1, they were told a story about a man named *Juffá*.

Teacher: *"Juffá gets a walking stick from a Noajdde woman (Sámi shaman) and this stick helps him when he gets into trouble, since it is then transformed. Sometimes it turns into a hook, and sometimes it can fly. And then we made walking sticks. They [the pupils] have their own walking sticks now."*

Through stories, and by comparing the past with the present and confirming what the children say, the teacher makes clear links between older and newer technological solutions.

Technology Project 3: The Sámi shaman drum – goavddis

According to the teacher, the Sámi shaman drum has never been a "magic drum", even if it was given that epithet by those who intended to eradicate the Sámi religion. The use of the drum was forbidden, and the drums were collected and burned. Not many have survived, but according to the teacher it is still a strong and important Sámi symbol.

The Sámi shaman drum, *goavddis*, had two functions in the past: 1) a tool that helped the Sámi shaman (the *Noajdde*) to enter a trance and travel to other worlds, and 2) an instrument to

help foretell the future. Common motifs on the drums are ancient Sámi gods and goddesses, reindeer, hunting, quarry animals and encampments (Kuoljok & Utsi, 2009).

The participants in the technology project about the Sámi drum are the year 3 pupils (aged 9). The Sámi drum project starts with a visit to the new town hall, and the teacher asks the pupils to memorise what the handles of the doorway look like. They are made of birch wood and reindeer horn. In the town hall's assembly room, a large decorative carpet on the wall depicts a drum, which the teacher asks the children to observe. Back in the classroom, the teacher introduces the technology project by showing pictures on the smartboard. The first is a photo of the town hall door handles (Figure 12).



Figure 12. The town hall door handles.

Teacher: "Why do the handles look like this?"

Pupil 1: "Drums."

Teacher: "That's right! They are made of birch and the white is reindeer horn, and there are engraved signs. They look like the bottom of an old drum, which the Sámi used. And what did they use them for?"

Pupil 2: "To know where to find reindeer grazing."

Teacher: "Yes... every family had a drum... it was used to see where to go with the reindeer, to make sure that childbirth went well, and where to find elk to hunt. With the help of the drum, they talked with the gods. Then there were those who were exceptionally good at it, the Noajddes [the shamans]... Then people from outside arrived. They were Christians and they said that [the Sámi] should not believe in this. The drums were collected and burned. One man was also burned when he refused to give up his drum. Some [of these people] thought the drums were nice... they brought them to Rome, Paris... to museums... Today only 71 remain. But last year they found one behind a stone. Someone had hidden it there. It had begun to rot."

The teacher shows a picture of a drum decorated with bear teeth.

Teacher: “The bear was sacred. If you slaughter a bear and remove the skin, it looks like a human... every symbol [on the drumhead] means something... Here’s a beaver, a reindeer corral, an elk, a hunter, a boat... What’s in the middle is the sun symbol, this cross. The symbols are popular today, they put them on mugs and on candles because think they are nice... but [people] do not know what they mean.”

The teacher presents pictures of drums decorated with illustrations of Sámi gods and goddesses and talks about the different roles they had in the mythology. The pupils receive a sheet of paper on which the gods’ symbols are depicted (Figure 13). They are asked to write down facts about six gods. Three goddesses live in the *lávvu*. In the conversations about the drum, the teacher and the pupils make connections to the *lávvu* project: the goddess who lives at the entrance to the *lávvu* and prevents evil spirits from entering the *lávvu*, the goddess who lives by the fire and protects the family and childbirth, and the goddess who lives in the sacred part of the *lávvu* and brings hunting luck, and who you ask for help if you want your unborn child to be a boy. (The teacher has told the pupils that the Sámi once thought all unborn children were girls.)

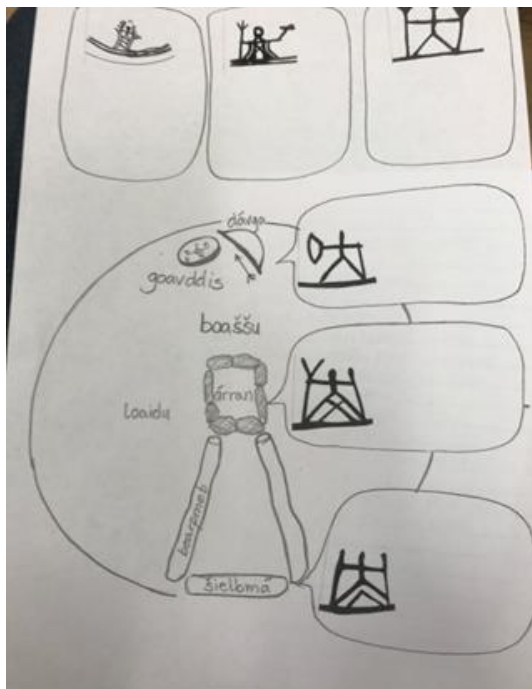


Figure 13. Sámi symbols of gods and goddesses.



Figure 14. Preparing the Sámi drum.

The teacher has prepared 12 concrete frames to form cylinders.

Teacher: “We’ll be stretching hide tomorrow, but you have to prepare. Paint any colour you like. When you have finished and it has dried, you can paint symbols.”

The teacher gathers the pupils around a table and shows them how to mix colours, and they start painting their drums (Figure 14). She has brought a hairdryer to dry the painted drums faster.

Teacher: “Here, I have a technical solution!”

The researcher assists the pupils and discusses the function of the drum.

Researcher: “Is the drum... technology?”

Pupil: “Yes, [it’s technology] because they [Sámi people in the past] used it to find grazing for the reindeer and to see how you could get well if you were sick.”

While decorating the drums with symbols, the teacher and the pupils discuss the historical illustrations (Figure 15). Just as with the sinew thread activity, the teacher links the past with the present.

Teacher: “They depicted things that were important to them. What symbols could be on the drum if it was used today? A car? A computer...?”

At the end of the lesson, the pupils are asked to write “a technology logbook”, where they will write down examples of technology they use during the course of a day. The teacher explains:

Teacher: “Yesterday, when I left school, I put on my shoes and my ice grippers... Is that technology?” (She asks the pupils to think quietly) “... And before I went to sleep, I turned on the tap and brushed my teeth with my toothbrush.”

The following day, it is time to attach the drumheads to the drums. The teacher has brought 12 circular reindeer hides. She gathers the pupils in a circle on the floor and demonstrates how the reindeer hides have been scraped with a specific tool and tanned in a decoction of water and willow bark.



Figure 15. *The pupils decorate their drums with symbols*

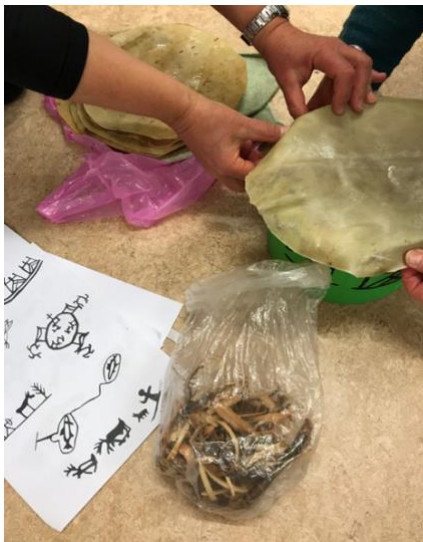


Figure 16. *The pupils explore the structure of the hides and the willow bark*

The hides are wet and are kept in a plastic bag, and the teacher explains that this is to stop them from drying out. The pupils explore the structure of the hides and how stretchable they are (Figure 16). The teacher then helps the pupils to attach the drumheads to the frames using a staple gun (Figure 17).

Teacher: *“But you will probably also have to fasten [the hides] with bolts and screws, and attach a ribbon over it. They will tighten as they dry.”*

While waiting for help to fasten the hide, the pupils are told to draw a drum on paper. The teacher says they are free to decorate it with old symbols, but they can also draw things that are important to them personally.

Teacher: "It was probably how they thought in the past, too."

Some pupils draw pictures of Sámi gods and goddesses, reindeer and Sámi dwellings, while others write the names of relatives and pets. The drums are then left to dry (Figure 18).



Figure 17. A staple gun is used attach the drumheads.



Figure 18. The drums are left to dry.

When constructing the shaman drums, as in the other two described activities, the teacher instructed the pupils and they imitated what the teacher did. However, the teacher also confirmed the pupils' alternative suggested solutions and encouraged them to personalise their drums by decorating them with illustrations that symbolise what is important to them personally and today. During the drum activities, the teacher and the pupils discussed both older and modern technological solutions to meet the same human needs and wants. For example, there is hospital technology today that can save mothers and children during complicated births. In the past, people had to rely on using their shaman drums and asking the

gods for help. In the past, reindeer herding used skis as the only means of transport. Today, modern technology such as snowmobiles, quad bikes, motorbikes and helicopters are used.

Identified themes

Through an interpretive analysis process of underlying meanings, based on Keirli's (2006) dimensions of technological literacy, and answering the questions *why*, *how* and in *what way* (Erlingsson & Brysiewicz, 2017), six themes emerged:

- Meaning-making through cultural artefacts
- Creating links between the past and the present
- Contextualisation through myths and storytelling
- A holistic view of technological knowledge
- Collective technological knowledge
- The symbolic value of technology

Meaning-making through traditional cultural artefacts

Technology education in this Sámi school can be described as being strongly connected to specific *traditional cultural artefacts*, exemplified in this case study through technology projects with the *lávvu*, the Sámi winter shoe and the shaman drum. By using artefacts with a strong connection to culture and a focus on 'how' the artefact is used and 'why' (James, 2015), the activities become meaningful for the pupils. The artefacts were presented as having both physical and intentional properties (de Vries, 2005; Kaplan, 2009; Kroes and Meijers, 2002), and as being a result of cultural conditions (Ihde, 1990, 1993; Kroes & Meijers, 2002; Vermaas et al., 2011). By using specific artefacts as a starting point for technology teaching, both historical and cultural perspectives were made clear.

This confirms that artefacts can play an important role in technology education (de Vries, 2005; Frederik et al., 2011). Previous research indicates that too strong a focus on artefacts can result in the connections between artefacts, humans and culture being disregarded (Mawson, 2010; Siu & Lam, 2005; Turja et al., 2009). However, the findings in this study demonstrate the opposite.

Creating links between the past and the present

In the teaching, there was a strong *link between the past and the present*, for example by comparing the *lávvu* with a caravan, shoe hay with socks and sinew threads with dental floss. The message was that although some knowledge is old, it remains important and relevant even today; new and old technology is often used side by side. Cultural artefacts mentioned during the technology lessons which have a long history but are still used include skin shoes, skis, reindeer skins as sleeping mats, traditional food technology methods, Sámi fishing methods, the traditional Sámi knife, and other artefacts connected to Sámi handicraft.

By using the cultural artefacts as a starting point in the teaching, the pupils were given the opportunity to see that technology is not only modern high-tech; it is an age-old tradition of problem-solving, modification and adaptation to fulfil our needs (Lee, 2011). The function of a technological artefact is often to extend our human capabilities (Lawson, 2008, 2010). Even if new technological solutions emerge and others disappear, there are also technological

solutions that remain and continue to be used (Edgerton, 2006; Kelly, 2010). In this way, technology's enduring dimension was highlighted (Axell, 2015).

The connections between older and newer technological solutions created opportunities for the pupils to develop an understanding of the driving forces behind technological development and change (Swedish Agency for Education, 2018).

Contextualisation through myths and storytelling

Myths and *storytelling* were important teaching elements in this Sámi school, and were frequently used to contextualise the technological content. For example, stories about *Stallo*, a common mythical figure in Sámi folklore, were a recurring element in teaching. The stories were largely conveyed orally by the teacher, but were sometimes already known by the pupils. These findings are in line with Owuor (2007), who notes that indigenous knowledge and skills are often transmitted from one generation to the next through narratives, symbols and art. The pupils also created their own fictional stories. This also confirms previous research suggesting that stories can be used in technology education to contextualise the technological content. Narratives and stories can act as springboards for discussions about the nature of technology and the driving forces behind technological change and its impact on society, people and nature in the past and the present (Axell, 2015, 2017, 2018).

A holistic view of technological knowledge

Technology education in this Sámi school was implemented using a thematic approach. In all three technology projects included in this study, the context was central and included both historical and present perspectives, with clear connections to other subject areas, such as science, religion, history and crafts, as well as other teaching activities. The fact that each technology activity was linked to many different perspectives and subjects indicates that technological literacy in this Sámi school is grounded on a *holistic view of knowledge*. It also confirms that indigenous knowledge systems are holistic (Keskitalo & Määttä, 2011; Keskitalo et al., 2012; Svonni, 2015).

Collective technological knowledge

During the activities, the teacher and the pupils frequently referred to contexts outside school. For example, several of the pupils testified that they knew how to build and use a *lávvu*, what reindeer sinews are used for, how the Sámi winter shoe is constructed, and what a shaman drum is. In the activities, the teacher also noticed and took advantage of the pupils' own experiences and knowledge. Additionally, the teacher's pedagogy was characterised by a "show-and-copy" strategy. This can be regarded as a natural choice in this context, since the technological knowledge linked to the specific cultural artefacts is passed on from one generation to the next.

The technological knowledge mediated in this Sámi school can thus be described as connected to inherited knowledge, but also linked to practical applications and skills (Keskitalo & Määttä, 2011; Keskitalo et al., 2012; Svonni, 2015). This confirms that indigenous technology is collective and based on knowledge that has been developed over many generations (Bondy, 2011; Gumbo, 2018). The fact that children bring their own technological knowledge and

understanding is an important aspect to be recognised by teachers in order to create relevant and authentic learning (e.g. Mawson, 2013).

The symbolic value of technology

In the activity with the shaman drum and in the *lávvu* project, connections between technology and religious beliefs were made clear. One example is when a pupil explained that the shaman drum is technology since the Sámi people previously used it to find grazing for the reindeer and to cure diseases. Historically, there has been a relationship between technology and religion. This aspect is highlighted by Cheek (2018), stating that if by *technology* we mean human activities that seek to meet human needs and wants by creating “the ever-evolving, human-designed environments” (p. 52), we can identify an interaction between religious traditions or practices and the goals, skills and methods of the technological world. Both technology and religion seek to solve human problems, fulfil human needs and improve human conditions. Even if the technological development is independent of any specific religion, religions have inspired technologies that support different belief systems (Cheek, 2018).

The teacher also pointed out the symbolic value of technology when she noted that the Sámi previously depicted things on their drums that were important to them, and suggested that a car or a computer could be possible decorations on a drum today.

Hence, technological knowledge, activities and specific artefacts included in technology education in this Sámi school are not only attributed a practical value, but are also given what can be described as a *symbolic value*. Artefacts are created to satisfy human needs and wants, but they also say something about us as individuals or as a group (Axell, 2015; Ellul, 1978; Kroes, 2012). The symbolic value of technology can also be linked to a sense of community and contributes to strengthening the Sámi children’s cultural identity.

Conclusions

In accordance with Keirl’s (2006) three important dimensions of technological literacy – *operational*, *cultural* and *critical* – the technology teaching described in this study included all three aspects. The pupils learned to use and do the technology, and their learning was contextualised through different kinds of narratives and references to their lives outside school and to Sámi culture. The critical dimension was also present. Using specific cultural artefacts as a starting point, comparisons were made between older and more recent technological solutions. However, modern technology was not portrayed as superior to older technology. The focus was rather to emphasise that the same human needs and problems can be solved with different kinds of technology, and that much of the technology that is still in use has a long history. By including indigenous knowledge in technology education, it is possible to avoid the technological version of the ‘Whig theory of history’, where the past is portrayed as an inevitable progression, driven by human progress where everything has only improved (Lee, 2011).

The three examples of technology projects in this study include aspects which are generally regarded as part of technology education, as well as aspects that are less common: indigenous technological solutions and the connection between religion and technology. In conclusion, this study confirms that artefacts can play an important role in technology education and that an

understanding of the relationship between technology and culture can be regarded as a critical part of technological literacy. A cultural context, in combination with a holistic perspective on learning, gives artefacts meaning and provides a context within which they are used. Including indigenous technological knowledge can thus not only prevent a marginalisation of indigenous knowledge, it can also provide opportunities to broaden pupils' horizons of what technology is, how it evolves, and the driving forces behind technological change.

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