Non-linear maker pedagogy in Finnish craft education

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This research explores the use of a non-linear maker pedagogy for implementing a major change in the Finnish national core curriculum. The latest curriculum change (2014) introduced so-called transversal competences, but also a major change for the subject of crafts: 'multi-material' crafts that involve former separately taught textile and technical crafts both now introduced to all pupils. These changes set the stage for in-service teacher training, as well as for pedagogical solutions, such as a non-linear maker pedagogy and closer collaboration between technical and textile craft teachers. A non-linear maker pedagogy refers to an approach combining several features: a shift from individual learning and solo teaching to collaborative knowledge-creating learning, opportunities for collective invention and improvisation, pupil-centred situated inquiry and the creation of artefacts that combine material and digital realms. In this collective case study, we interviewed six teachers who co-taught non-linear maker projects in six different schools. Through a qualitative content analysis, we identified successes and challenges regarding the use of a non-linear maker pedagogy, pupil collaboration and teaching digital skills through robotics and e-textiles. In the interviews, teachers reflected on their work mainly by describing their pupils' accomplishments, reactions and learning. These reflections indicated similar challenges and successes, suggesting that the variation between pupils and pupil groups was larger than that between schools. Furthermore, we discuss whether the selected pedagogical approach was unduly ambitious. Despite all the challenges, most of the teachers expressed their commitment to developing their teaching practices along the lines of a non-linear maker pedagogy.

Keywords: Co-teaching, Curriculum change, Digital skills, Non-linear maker pedagogy, Pupil-directed situated inquiry

Introduction

Many countries continue to pursue school reforms towards 21st-century competences (for a review of the frameworks, see Binkley et al., 2012; Dede, 2009; van Laar et al., 2017). Still, research suggests that the usual teaching approaches include teachers transmitting factual knowledge (Saavedra & Opfer, 2012), pre-determined skills and scripted procedures (Thumlert et al., 2018) to pupils. This transmission model of teaching offers pupils only a few opportunities to apply 21st-century skills creatively in new contexts (Saavedra & Opfer, 2012) or to take initiatives and regulate their own learning and doing. To prepare new generations of pupils and teachers for our rapidly changing society and capitalise on the novel pedagogical possibilities of digitalisation, educational institutions need to change. Definitions of 21st-century skills commonly emphasise higher-order thinking, collaboration and communication, and the use of technology to create new knowledge and expand human capacity (Binkley et al., 2012). These 21st-century skills need to be mastered by the teachers themselves before they can develop effective pedagogical models to teach such skills. Moreover, schools must support teachers' professional development and become learning organisations for both pupils and teachers alike (Saavedra & Opfer, 2012).

To respond to the crucial role that creativity and design will play in future society, the latest National Core Curriculum for Basic Education in Finland (FNCBE) (Finnish National Board of Education, 2014) emphasises creativity, innovation and digital skills. These skills are seen as transversal and interdisciplinary competences that are embedded in each school grade and subject. The FNCBE recognises seven transversal competences: thinking and learning to learn (T1); cultural competence, interaction and self-expression (T2); taking care of oneself and managing daily life (T3); multiliteracy

(T4); ICT competences (T5); working life competence and entrepreneurship (T6); and participation in, involvement in and the construction of a sustainable future (T7). These transversal competencies have a cross-curricular nature to be introduced in the local subject-specific curriculum and to be included yearly in at least one multi-disciplinary module (a phenomena-based project or unit, examples of which are provided in Korhonen et al., 2022). Thus, the curriculum shifts the focus from subject-specific content knowledge (what teachers should teach) to teaching more general competences.

In Finland, craft education has been an important part of the curriculum for over 150 years, providing children with learning through embodied material interactions (Seitamaa-Hakkarainen & Hakkarainen, 2017; Porko-Hudd et al., 2018). In the latest curriculum change (2014), the major change for the subject of crafts was that the pupils' option to choose between the former separately taught content areas – textile and technical crafts – was withdrawn, and 'multi-material' crafts was introduced to all pupils. Overall, the latest FNCBE changes provide opportunities for the implementation of the makerspace philosophy and maker pedagogy in the Finnish subject of crafts. The term 'makerspace' refers to a physical space where people participate for the creative purposes of making artefacts (Halverson & Sheridan, 2014). Makerspace philosophy emphasises the democratisation of knowledge and power, open-ended maker projects, creativity and design thinking, as well as support from peers, the community and experts (Sheridan et al., 2014). This philosophy is seen as distinct from structured, formal learning environments such as schools (e.g., Halverson & Sheridan, 2014; Konopasky & Sheridan, 2020); for instance, the need to grade pupils' work can deter teachers from encouraging collaborative and open-ended projects. Makerspaces emphasise informal learning and encourage purposeful tinkering and inquiry with others, whereas learning in schools is more pre-planned and guided by teachers (Halverson & Sheridan, 2014; Konopasky & Sheridan, 2020; Martinez & Stager, 2013). Many countries have organised new makerspaces (Gutwill et al., 2015; Halverson & Sheridan, 2014; Weiner et al., 2020). However, available research on makerspaces in schools is still limited, as nationwide initiatives related to technology literacy, design and makerspaces in Sweden (Eriksson et al., 2017) and in Denmark (Tuhkala et al., 2019) have also noted.

The unknown future, with its rapid technological and material developments and digitalisation, calls for strategic pedagogical methods and teaching practices associated with the orchestration of sustainable and collaborative maker projects, also in basic education. For the subject of crafts, the curriculum does not provide any more guidelines on what materials and techniques should be used in crafts; this change has been experienced as challenging by teachers (Kokko et al., 2020). To address these demands on teaching, we propose a non-linear maker pedagogy for teaching 21st-century skills and innovative making practices. The non-linear maker pedagogy is outlined below, while the theoretical background is described in the following chapter.

A non-linear maker pedagogy shifts individual learning to collaborative work, emergent processes, interdisciplinarity and multiple ways of knowing, often extending school subject boundaries. The word 'collaboration' has several meanings. In this context, collaboration involves group work with a mutually shared understanding, a division of the work and organisation of the shared processes (Damsa et al., 2010). For Finnish multi-material crafts, this offers a twofold opportunity to collaborate. For pupils, it provides the possibility to extend collaboration (peers, tutors or other stakeholders) during craft lessons, and for teachers, this affords opportunities for teacher collaboration in all three phases of teaching: co-planning, co-instructing and co-assessing – that is, co-teaching (Murawski & Lochner, 2011). With a non-linear maker pedagogy, actual goals, objects, stages, tools or end results cannot be fully pre-determined or scripted (Sawyer, 2018); teachers need to tolerate the partly unpredictable and ambiguous nature of non-linear processes. For teachers, the implementation of a non-linear pedagogy requires courage and the competence to develop new ways of teaching (Kangas et al., 2022). To support the implementation of a non-linear maker pedagogy, we propose co-teaching, a pedagogical practice for teacher professional development (Rytivaara et al., 2019), which is frequently utilised during educational reforms and transformations (a review by Härkki et al., 2020). However, current research is lacking in terms of detailing how teachers implement a non-linear maker pedagogy and how they orchestrate non-linear maker projects, either individually or in collaboration with their colleagues.

From these premises, this research explores the use of a non-linear maker pedagogy in order to implement a major change in the Finnish national core curriculum. The change, in this particular case, is understood as the introduction of collaborative group projects and digital technologies, such as robotics and e-textiles, into craft teaching. To that end, we posed the following research question:

What are the successes and challenges of a non-linear maker pedagogy in Finnish craft education from the teachers' perspective?

In the following sections, we briefly review the theoretical underpinnings of a non-linear maker pedagogy that guided our empirical research on projects aiming to develop pupils' 21st-century and transversal skills. Next, we present our methodological approach. Finally, we synthesise the theoretical insights with findings from the empirical data on teachers' approaches to this non-linear pedagogy.

Non-linear maker pedagogy

Traditionally, teaching has often been a predictable process, involving organising what is to be learned into appropriately sized and sequenced pieces, and arranging optimal methods of delivery to ensure that all pupils acquire these pre-defined skills or knowledge (Wells, 2008). This kind of pedagogy is characterised as linear because pupils work with pre-defined problems through scripted and pre-established procedures, methods and outcomes (Sawyer, 2018). However, new learning theories and modern methods call for major changes in the ways in which education has been organised in the past.

A non-linear maker pedagogy involves a shift from individual learning and solo teaching to collaborative knowledge-creating learning (Härkki et al., 2020). Higher-level learning objectives, such as reflective thinking and collaboration, rather than pre-defined skills or knowledge to be mastered, are emphasised. Pupils engage in open-ended learning activities to solve design tasks that are ill-defined, authentic and challenging (Seitamaa-Hakkarainen et al., 2010). While collaboratively developing new innovations, pupil teams handle versatile and sophisticated epistemic issues, ranging from making tangible objects to STEAM phenomena powerfully linked to making practices (Honey & Kanter, 2013; Korhonen et al., 2022; Martinez & Stager, 2013). Pupils formulate and modify emergent goals while pursuing them (Scardamalia et al., 2011), intentionally introducing multiple ways of working, thinking and making. This requires time to experiment, develop and test solutions iteratively (Markauskaite & Goodyear, 2016; Sawyer, 2011), within time and budget frames set by the teachers but carefully tailored to balance the needs of the pupils and curriculum.

Research has shown how engaging in makerspaces enhances pupils' creativity and imagination (Burke & Crocker, 2019), design thinking (Clapp et al., 2016) and learning in STEAM subject areas (Petrich et al., 2013). These studies have revealed the importance of socio-materiality and embodied knowing in making, thus making the subject of crafts an ideal context. Maker pedagogy combines traditional and digital tools and technologies as mediums: pupils are introduced to fabrication technologies such as 3D CAD and 3D printing, electronics, robotics, programming and wearable computing with various sensors (e-textiles) through which they may create multifaceted and complex artefacts (cf. Blikstein, 2013; Blikstein & Worsley, 2016). Such technologies enable pupils to construct complex, controllable artefacts using hybrid materials, incorporating digital and virtual features. However, there is a lack of research on how learning by making can be used in pedagogical practices for systematically educating learners in creativity and innovation in basic education (Halverson & Sawyer, 2022; Sawyer, 2018). Based on our previous and ongoing projects, we (Seitamaa-Hakkarainen & Hakkarainen, 2019;

Hakkarainen & Seitamaa-Hakkarainen, 2022) have highlighted the key differences between a linear pedagogy and non-linear pedagogy in Table 1 (see also Sawyer, 2018). Examples of implemented non-linear maker projects can be found in Korhonen et al. (2022).

Table 1. Key differences between a linear pedagogy and non-linear maker pedagogy (see Seitamaa-Hakkarainen & Hakkarainen, 2019).

Element	**Linear pedagogy**	**Non-linear pedagogy**
Higher-level learning objectives	Transmission of specific skills, knowledge, or techniques	Development of transversal/21st-century skills
Learning task	Pre-defined goals and solution models	Open-ended and partly ill-defined goals and solution models
Information resources	Pre-defined ('pushing' knowledge)	Open and extended ('pulling' knowledge on demand)
Structuring	Scripted models of action, though some improvisation could be involved	Adaptive structuring and improvisation on action
Modelling	Pre-defined models, reproduction	Elements of invention combined with design constraints
Scaffolding	Error elimination	On-demand scaffolding
Context	Usually school-based	Extends boundaries of school learning, increases unpredictability
Assessment	Summative assessment of outcomes	Formative assessment throughout learning process
Gradually deepening problem solving	Teacher has the opportunity for gradually deepening problem solving as he/she structures learning materials	Everyone is required to participate in deepening problem solving and learning through creative failures

Some maker pedagogy learning tasks involve pre-defined outcomes and an imposed form, which delimit pupils' creativity and agentive forms of critical inquiry (Thumlert et al., 2018). Contrastingly, a non-linear maker pedagogy involves artefact-mediated design and craft processes in which neither objects, stages, tools nor end results can be pre-determined, nor can the flow of creative activity be scripted (Sawyer, 2018). Therefore, teachers can no longer rely on pre-established procedures when planning the process of teaching, nor standardised testing of specific content knowledge or skills. Teachers need to balance the structuring of a non-linear maker project flexibly according to the ideas and practices that emerge throughout the project (Sawyer, 2011; Viilo et al., 2018).

Dealing with such uncertainty with adaptive orchestration and on-demand scaffolding to support each class's unique aims and projects is essential (Viilo et al., 2018). Sawyer (2011) described such an adaptive process of teaching and learning as collective improvisation and invention: teachers and pupils are also collaboratively generating knowledge practices and an environment that affords their evolving process of learning and collaboration (Markauskaite & Goodyear, 2016). The adaptive and flexible structuring is based on the idea of scaffolding (Wood et al., 1976); that is, providing students with contextual guidelines or supporting structures for carrying out more complex activities that would otherwise be difficult to achieve. The scaffolds vary from technical scaffolds (such as worksheets) to social scaffolds (such as prompts and gestures) provided by teachers. Teachers need to act as facilitators who support pupils' learning activities by asking questions, modelling and explaining how things work (Gutwill & al., 2015; Petrich et al., 2013). This requires the improvement of ideas through dialogue and action. This teacher facilitation is a central component of maker projects: The challenge lies in keeping the balance between scaffolding and fading, that is, offering sufficient support to pupils while maintaining enough distance to support self-directed activity (Härkki et al., 2020). However, research on teachers scaffolding these non-linear processes is scarce; exceptions include Viilo et al. (2011, 2017, 2018).

Altogether, a non-linear maker pedagogy sets a demanding challenge to transform existing practices of planning, instructing, assessing and working with socio-digital learning environments. Moreover, breaking the boundaries of school learning as well as school subjects provides novel opportunities – even demands – for teacher collaboration.

Research design

To support craft teachers in curriculum implementation, the Ministry of Education and Culture initiated a national-level development programme. This research was conducted during the second development cycle of a two-cycle programme (2017–2020) that invited teachers to co-innovate pedagogical practices rather than merely implement them. Teachers chose their own training sessions and the elements they would introduce to school projects, while the programme introduced co-teaching, and structures suitable for non-linear maker projects supported by practical workshops and training in relevant digital technologies.

Research participants

The data for this collective case study (Goddard, 2010) was selected from a larger dataset by using purposeful criterion sampling, which aims at the effective use of limited research resources by narrowing the range in variation (Palinkas et al., 2015). Six projects completed during spring 2019 were selected based on the following similarity criteria: all pupil groups had engaged in open-ended learning tasks and learning robotics, and teachers had learned new technologies and had co-taught (Table 2). Variation between cases was provided by the geographical location of the schools (rural and metropolitan basic education schools included), the duration of the projects and the length of teachers' experience in collaborating with each other. Only one project per school was included in this study.

Table 2. Teacher teams, school projects and involved technologies.

Teachers	Project name	Grade	Duration	Technologies	
			(Months)	e-textiles	Robotics
A & J	Everyday challenge	6a, 6b	4	No	Circuit Playground
M & V*	Everyday challenge	7a, 7b	5	No	Circuit Playground
H & L*	Everyday challenge	7a, 7b, 7c, 7d	5	No	Circuit Playground
M & H	Everyday challenge	8	2	Yes	Circuit Playground
L & M	Space adventure	1 & 5	5	Yes	Arduino Nano
N & T^	Safety product	7	5	Yes	Arduino Nano

Participants were either craft subject teachers or class teachers who also taught crafts. All but one teacher team (marked ^ in Table 2) had not co-taught at this level of sharedness. Eight teachers had more than 10 years of teaching experience, and two (marked * in Table 2) had less than 2 years' experience. All but one teacher participated in half to one day of introductory training sessions in their chosen technologies. All participation was voluntary, and the participants signed an informed consent form before the interviews.

An example of an implemented non-linear maker project is presented in Figure 1: a 4-month learning project, an everyday challenge for Grade 6. The pupils visited a museum to study a foreign culture of their own choosing. In groups of two to three, they were challenged to design and make an everyday smart artefact by using stimuli from this culture, and to lock in a digital factor, such as sound, light or movement. The pupils practiced techniques related to e-textiles and sensor technology, and brainstormed and developed preliminary ideas through sketching, modelling and technology explorations. After they were ready to settle on a concept, they developed prototypes. Plans, material needs and prototypes were introduced to the whole class for feedback. Several iterative rounds of finetuning, making and testing were followed by an Innovation Fair that was organised for the class. The pupils documented their plans and progress in an ePortfolio shared by all group members (Saarinen et al., 2019). Examples of smart artefacts designed and made by pupil groups are shown in Figure 2.

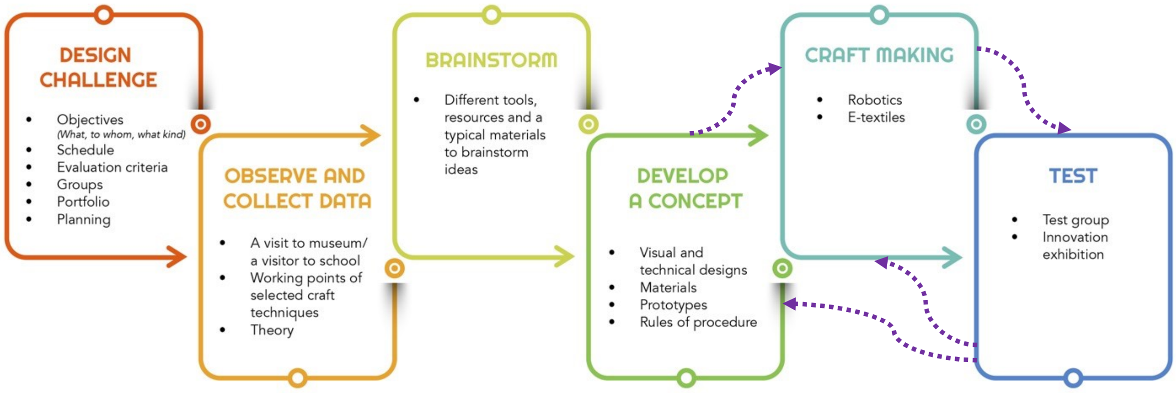

Figure 1. Everyday smart artefact challenge for Grade 6. The task began with more structured phases to ensure that all pupil groups had a basis for their work. Starting with concept development, pupil groups' work had a more iterative character: developing designs and prototypes, implementing robotics and e-textiles, testing and making changes. The lilac dotted arrows represent the pupil groups' iterative work.

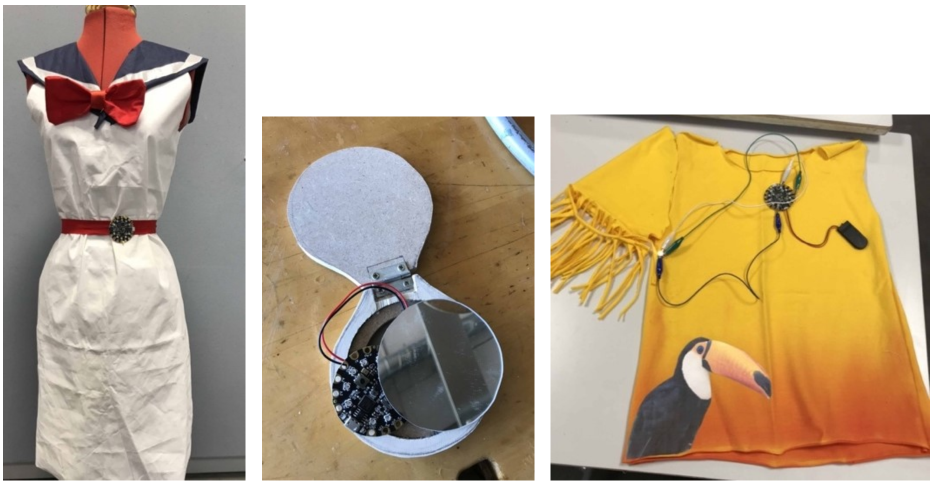

Figure 2. Examples of everyday smart artefacts named by the pupils. Left: Korean school dress with a flashing light instead of a bow in the waist. Middle: A Revealer inspired by Canadian Mountain Rangers that guards and keeps people and their belongings safe. The Revealer can guard one's room (or, for instance, a bag) and notify its owner if someone comes too close, as it has a motion sensor and alarm. Right: Brazilian toucan shirt with LED lights sewn into the seams.

Data collection and analysis

The teacher teams were interviewed by experienced interviewers at the end of the school projects. Semi-structured interviews (Kallio et al., 2016) were based on an interview guide to ensure sufficient comparability between teams (Barribal & While, 1994), yet teachers were given the freedom to discuss issues they experienced as relevant. The topics covered in the interview guide included project planning, co-teaching, structural support and the non-linear pedagogy. In total, the interviews produced five hours of audio data that were transcribed verbatim.

Data analysis followed the collective case-study method (Goddard, 2019), as detailed by Crowe et al. (2011), and principles of qualitative content analysis (Elo & Kyngäs, 2008). The transcripts were read closely several times to gain a thorough understanding of each case. The teachers spent most of the interview time talking about their pupils: the teachers measured and described their own successes and challenges through their pupils' learning, reactions and struggles. At times, the teachers reflected on their emergent co-teaching practices. These data were first coded by open coding as successes and challenges. A description was coded as a success when a teacher was satisfied, pleased or content with the event or practice, and as a challenge when he/she or the pupils had struggled or felt significant uneasiness. In phase two, these successes and challenges were then deductively coded according to categories (elements of a non-linear maker pedagogy) listed in Table 1. To complement this categorisation, two inductively derived categories were added: pupil collaboration and digital technologies. These two phases of the data analysis process, the categories and examples are summarised in Table 3.

Table 3. Three phases of the data analysis process and the development of the categorisation. Italics refer to specifically relevant parts of the category in question.

Phase	Category	Examples
1: Open coding		
	Success: A teacher was satisfied, pleased or content with the event or practice.	A: *The pupils said that they liked* this novel way of working. [*For them,] It was nice to* a) work in pairs and b) not to know in the beginning what you would end up making. (A&J, 33)
	Challenge: A teacher or pupils struggled or felt significant uneasiness.	J: Then we set constraints for making and what can be done, but *we also have to be able to say to a pupil, no, that cannot be done, you need to change your plans*. And that is for some, well, some pupils *like bumping into a wall.* (A&J, 45)
2: Deductive coding		
	Higher-level learning objectives: Developing transversal/21st-century skills	(A success) L: We discussed that this is exactly how the projects *required by the new FNCBE* should be. (H&L, 30)
	Learning task: Open-ended, partly ill-defined goals and solution models	(A challenge) H: We should recognise the pupils that actually *require modelled tasks*, those who just could not … get started with *an open task.* (M&H, 24)
	Information resources: Open, extended (pulling on demand)	(A success) M: *The designer* starting the project [...] *pupils asked many [extra] questions of her, wanting more*. (M&H, 6)
	Structuring: Adaptive structuring and improvisation on action	(A challenge) H: *We should recognise the pupils* that actually require modelled tasks, those who just *could not … get started* with an open task. *They need to hear what they should do*. (M&H, 24)
	Modelling: Elements of invention combined with design constraints	(A challenge) J: Then *we have constraints* for making and what can be done, but we also have to be able to say to a pupil, no, that cannot be done, you need to change your plans. And that is for some, well,

		some pupils like bumping into a wall. They just cannot *find other solutions*. (A&J, 45)
	Scaffolding: On-demand scaffolding	(A challenge) J: Then we have constraints for making and what can be done, but *we also have to be able to say to a pupil, no, that cannot be done [due to being too laborious considering the time-frame], you need to change your plans*. And that is for some, well, some pupils like bumping into a wall. They just cannot find other solutions *[without the teacher's advice*]. (A&J, 45)
	Context: Extends boundaries of school learning, increases unpredictability	(A success) M: All learning tasks in *the Design museum* were fun, spot an innovation, for instance. One group *wanted to visit the museum several [extra] times, very inspired*. (M&H, 15)
	Assessment: Formative assessment throughout learning process	(A success) A: *Pupils updated their electronic portfolios constantly during the project*, and *we followed [and commented on] their updates*. (A&J, 32)
	Gradually deepening problem solving: Participation in deepening problem solving and learning through creative failures	(A success) M: Some pupil groups could be *really persistent; they experimented, tested, reiterated, made again*. For some groups, it was maybe the best phase, experimenting and testing. They learned. (M&H, 43)
	Collaboration: Mutually shared understanding, division of the work and organisation of the shared processes	(A challenge) L: *The pupils were so reluctant …* Maybe later, *maybe they did become more positive* after several months. Now, in retrospect, one can say that *supporting group work was the most, the most difficult task.* (H&L, 14)
	Digital technologies: Used technology mentioned	T: When thinking about *Arduino,* some pupils probably can apply their learning in their own everyday lives. (N&T, 8)

Findings: Successes and challenges of a non-linear maker pedagogy

In the team interviews, the teachers evaluated their accomplishments and identified further development needs by describing and reflecting on pupils' reactions and achievements. It was typical of these six cases that *differences between individual pupils and pupil groups were larger than differences between classes or schools*, and *almost all classes encountered the same successes and challenges to differing degrees*. This main finding is detailed in each section. To present the study findings, categories that were regularly linked with each other in the teachers' descriptions were merged.

Higher-level learning objectives

Higher-level learning objectives frequently included transferring previous skills and knowledge to new contexts and tasks, as well as collaboration skills, with which all the teachers were content.

> J: These projects somehow facilitate working from a long-range perspective.
> A: Long-range perspective and collaboration.
> J: And problem solving. Constant problem solving.
> A: […]. Learning how complicated life is, in general. (A&J, 41)

> T: When thinking about Arduino, some pupils probably can apply their learning in their own everyday lives; they might now understand the world around them a little bit better. (N&T, 8)

All the teachers discussed at length the challenges that *some pupils, but not all,* had in transferring their learning. Coding learned during mathematics lessons came up in three interviews as an example of a challenging knowledge transfer.

> H: [These] Pupils' transfer of knowledge … If you learn [coding] in maths, it's not available for crafts lessons. [The pupils] are like, 'What? Never heard of it.' Should one of us [craft teachers] stand there in the maths class to show that there is a connection? So they couldn't say, 'This is maths.' This is interesting because it's connected to many other things, too. The pupils are like, 'Never heard of it, no idea what a ruler is, especially what to do with it.' (H&L, 8)

Learning tasks and structuring

All the teachers had noticed that novel tasks inspired *many pupils*, and that when successful, co-creation appeared very rewarding for pupils. According to three teachers, *some pupils* were inspired by the absence of right or wrong solutions, which gave them the freedom to experiment.

> A: The pupils said that they liked this novel way of working. It was nice to a) work in pairs and b) not to know in the beginning what you would end up making. (A&J, 33)

Eight teachers had noticed that *some pupils* had difficulty accepting that they had to change their plans in the absence of applicable solutions.

> A: We had too many iteration and feedback rounds during planning. Pupils at this age, they cannot wait; they want to start making. (A&J, 4)

> J: Then we have constraints for making and what can be done, but we also have to be able to say to a pupil, no, that cannot be done, you need to change your plans. And that is for some, well, some pupils like bumping into a wall. They just cannot find other solutions. (A&J, 45)

All the teachers highlighted that *while some pupils excelled, some tasks were too difficult for some pupils or age groups*, which the teachers interpreted as a requirement for further fine-tune learning tasks and adaptive structures.

Modelling and scaffolding

Eight teachers described how these co-creation projects made it uncomfortably clear for them that *some pupils* were unable to work without stepwise instructions or to create artefacts with no material precedent. For *some pupils,* the project requiring creative skills and problem solving represented a novel learning task, different than they had previously encountered. More scaffolds were needed. Yet, seven teachers had noticed that for *some pupils*, the early difficulties turned into learning experiences, and they took pleasure in their accomplishments.

> H: We should recognise the pupils that actually require modelled tasks, those who just could not … get started with an open task. They need to hear what they should do. (M&H, 24)

> H: This new craft, for [some pupils] who aren't [accustomed to] imaginative or cognitive work … planning is not their strong point. For those, this was really difficult; it was really difficult for them to imagine what they should do. […]. However, this leaves such a good feeling, and you can see such a tremendous, in some groups, tremendous change and development. The final artefacts were completed and functioned well and such … And collaboration started to function, so there was a light at the end of the tunnel. […] I'm one hundred percent behind these learning objectives. Seriously, these are the objectives that pupils at that age should be able to reach. (H&L, 16)

As each pupil group was working on a different project and had different needs, the need to orchestrate and facilitate the whole class while providing appropriate and adaptive scaffolds for individual pupils caused all the teachers to feel overwhelmed, at least occasionally.

> H: Earlier, you didn't have to control so many things simultaneously, but now you have in a class, for instance, 16 different projects. (M&H, 41)

The major challenge for non-linear maker projects is that some of the required tools, materials and skills need to already be familiar to the pupils, yet these needs cannot be entirely determined in advance, due to the open-ended character of the projects. Teachers need to react and change plans quickly.

Information resources, context and gradually deepening problem solving

Teachers' descriptions of information resources, expert visits and extramural learning environments were rather neutral, having elements of neither successes nor challenges. All teachers had noticed gradually deepening problem solving manifest, especially during the experimentation and testing phases.

> M: Some pupil groups could be really persistent; they experimented, tested, made again. […] For some groups, it was maybe the best phase: experimenting and testing. Unlike when the artefact was finalised. I think that those groups understood the value of those earlier phases. I believe that they learned. (M&H, 43)

According to five teachers, seeing other groups' work encouraged *many pupils* to broaden their experiments and testing – to switch from surface-level working to deepening problem solving.

> A: When experimenting, pupils benefited from seeing [each other's experiments] and the variations in experimenting. Some experimented only on a surface level, while others were deeply focused on finding different solutions, and it was wonderful to see how many pupils [noticed] that hey, should we be doing it like that too? (A&J, 35)

Although temporarily frustrating to pupils, with seemingly overwhelming challenges due to working with unfamiliar technologies, encountering unanticipated construction problems and carrying out projects leading in unforeseen directions, non-linear maker projects offer unique learning opportunities for gradually deepening problem solving.

Evaluation

All the teachers thought that having two teachers conduct the evaluation together resulted in more objective and fairer grading. Pupil evaluations were partly based on their process portfolios and partly on the created artefacts. However, *many pupils* needed constant encouragement to document and reflect on their processes during lessons, and time had to be reserved for portfolio work.

> A: Pupils updated their electronic portfolios constantly during the project, and we followed their updates. They use colour codes to indicate if a goal is achieved, and when it is, they move over to the next task. This was part of the evaluation: how well the portfolio reflected the work process. […] We both [teachers] gave numerical grades and then we checked whether we were in agreement. We also evaluated pupils' prototypes, and we had evaluation discussions with pupils. (A&J, 32)

In addition to providing grounds for teachers to evaluate pupils' processes, portfolio work reflected how pupils took responsibility for their own learning and making processes.

Successes and challenges regarding pupil collaboration

There was a wide consensus among teachers that group work provided valuable learning experiences for pupils. All the teachers had noticed that *some pupils* seemingly enjoyed working together, but others resisted group work.

> L: It was a burden; some pupils were really negative in the beginning. It was not about the design task but–
> H: Group work.
> L: Yes. The pupils were so reluctant … Maybe later, maybe they did become more positive after several months. Now, in retrospect, one can say that supporting group work was the most, the most difficult task.
> H: Maybe it's actually about us having so little group work in crafts that it might be that the teacher … or up to myself to know how to use the groups and all the basics [of collaboration]. I thought they would work, but they didn't. (H&L, 14)

Group-level improvisation required flexibility and co-regulation from pupils, which *most of them* were still to learn.

> M: Well, some groups required a really, really supportive, active teacher presence. [...] in general, basic education pupils need teacher presence and maybe some help in throwing ideas around so that they can see the variety and then choose. (M&H, 34)

Extensive teacher support was required, and supporting co-regulation proved to be one of the most difficult aspects of these projects. This experience was shared by all the teachers.

Successes and challenges of digital technologies

According to half of the teachers, pupils welcomed e-textiles, but robotics proved divisive – inspiring and highly motivating for *some pupils*, but rejected altogether by some. However, some of that initial resistance transformed into enthusiasm when the pupils saw their creations ready and working.

> M: The children put up rather strong resistance; they would have preferred traditional crafts.
> L: They thought it was really difficult and challenging and they had to think so much…
> M: No motivation for this!
> L: Yet in the end, they were really happy when the lights lit up. (M&L, 25)

All the teachers shared the concern that in pupils' projects, technological solutions did not achieve the targeted level of learning (e.g. 'smartness' based on sensors) because learning tasks were not adequately constrained or scaffolded, and because of *some pupils'* lack of motivation. Then again, the teachers recognised that *some pupils* were frustrated because their designs were too ambitious for their skills.

> T: Rather safe choices [the pupils] made. I'd have expected a more courageous approach, challenging oneself.
> N: Maybe, if we'd settled for prototypes and not asked for final artefacts, they could have made more courageous choices, as they didn't have to fear that they didn't have the necessary making skills. (N&T, 10)

All teachers had to learn novel technological skills for these projects: coding, 3D printing and e-textiles. Teachers received support from their co-teaching partners, and sometimes from larger teacher communities.

> L: Well, at least for me … I tried to remember how an electric circuit was connected and sewn [...].
> M: Well, we pondered in a larger teacher group [laughter] one day about how these wires should be connected. (M&L, 20)

> M: And when I quickly tried to solve the problem, it didn't work as I thought. Like these sensors, how to connect or code, more [info] is needed. They have good support sites, but the needed [info] isn't exactly available. (M&V, 45)

Six teachers had noted that coding and robotics, which are not dedicated to any of the traditional craft learning environments, and which were relatively new to all teachers, allowed more equal sharing of co-teaching responsibilities between technical and textile craft teachers.

> N: In this project [coding with Arduino Nano], each of us can take full responsibility for these seventh graders whenever necessary. (N&T, 5)

All but two teachers expressed that incorporating robotics and e-textiles into craft teaching could clearly benefit from a better availability of technical support, such as longer training sessions, better support pages on the internet or on-site support at schools.

Discussion and conclusions

To study the implementation of a national-level curriculum change, we chose six schools, four of which were located in the capital region and two in rural eastern Finland. The two sets of cross-sectional interview data were collected when the non-linear maker projects were just finalised (or just about to be finalised); the teachers' experiences were still fresh in their memories. Due to the semi-structured interviews and the interviewers being known to the teachers, the interviews had an informal atmosphere in which the teachers could lead the conversation towards issues that were significant for themselves. A case-study approach is considered suitable for capturing how a change is implemented in the field (Crowe et al., 2011). In this study, cross-case comparisons between the six co-teaching teams' experiences provided the basis for data triangulation. Classroom video data were available from some schools but not utilised in this study. This was due to the fact that, for all six projects lasting nearly an entire spring semester and located in different schools, organising observations that would provide a secure base for data triangulation proved beyond the limits of the programme. Furthermore, due to teachers' scheduling difficulties, we could organise only one cross-sectional interview round.

In the team interviews, the teachers described the unfolding of their non-linear maker projects mainly by describing pupils' reactions, struggles and achievements; that was the teachers' way of measuring their own successes and challenges in tailoring non-linear maker projects to the needs of their pupil groups. In general, the non-linear maker pedagogy appeared to deliver according to the reformed curriculum, but not without difficulties. Teachers experienced several elements of the non-linear pedagogy both as challenges and as successes, depending on the pupil (or pupil group) in question. Combining open-ended learning tasks, ill-defined goals and knowledge demands defined by pupils' projects (rather than a pre-defined agenda) emphasises the need to carefully observe pupils' needs and to provide the necessary scaffolding and information resources for as long as they are needed. Adaptive structuring and improvisation on action represent teaching skills that need practice.

On the positive side, teachers noticed that the projects offered learning experiences for many pupils, which Bergman and Kostenius (2018) have coined meaningful: The learning was shared, and pupils recognised their own growth and achievement through hard work, which fostered positive feelings and increased confidence. Especially at the project-end Innovation Fairs, pupil groups could make their learning visible and proudly present their smart artefacts. This kind of social recognition is in line with the ideas of maker pedagogy that emphasise students' agency and empowerment (Sheridan et al., 2014), as well as FNCBE transversal competences.

A major difference between this approach to a non-linear maker pedagogy and the initiatives to introduce digital fabrication and makerspaces in schools in Sweden (Eriksson et al., 2017) and Denmark (Tuhkala et al., 2019) is that a non-linear maker pedagogy is about pupils working collaboratively in groups, not individually. Teachers are challenged to master novel ICT and digital skills (Eriksson et al., 2017; Tuhkala et al., 2019), but for the interviewed teachers, this was not the most challenging aspect. The projects introduced learning tasks that were unfamiliar to these pupils, which showed variations in pupils' capabilities. Teachers reported observing underperformance, to which they responded by finetuning, if not radically changing, plans during the project in mid-air. Teachers treated this as a positive challenge in finding more suitable and scalable learning tasks and support structures. Especially for teacher teams with a functioning co-teaching relationship and a shared commitment to principles of the non-linear maker pedagogy, setbacks were seen as positive: interesting opportunities to learn and develop one's teaching.

The most frequent challenges were related to pupil collaboration and shared regulation of the group work: working as a group, and taking responsibility independently rather than by relying on a teacher to tell one what to do and determine who should do it. This corroborates the findings of Braskén, Hemmi and Kurtén (2019) and of our recent study (Riikonen et al., 2020): the collaborative creation of knowledge and gradually deepening problem solving appeared to be critically dependent on pupils' engaging in embodied making rather than in mere discussions about ideas, as well as on pupils who collectively took responsibility for the co-invention process. This importance of active engagement is in accordance with previous research (Damsa et al., 2010; Scardamalia & Bereiter, 2014a). Moreover, in collaborative projects, teachers used to tailoring scaffolding activities according to the needs of an individual pupil – one at a time – face several pupil groups, each with its own mixture of needs. Some teachers described at length their aims to compose the pupil groups (heterogeneous versus homogeneous with respect to performance level or friendship) in such a way as to mitigate the challenges regarding scaffolding pupil groups, but none reported a solution with which they were content. Furthermore, several teachers anticipated that because pupils were used to group work in other subjects, those skills could be transferred to crafts. However, it could be that the broad use of group work does not automatically yield high-level collaboration skills in pupils, but deliberate teaching of collaborative practices is required (Hennessy & Murphy, 1999; Warwick et al., 2013). The transfer of knowledge and capabilities is central in the definitions of 21st-century skills and in the FNCBE. Some teachers discussed at length their disappointment regarding this transfer. For instance, applying basic coding skills learned in mathematics appeared difficult outside of mathematics classrooms. Once again, this finding corroborates the findings of Braskén et al. (2019).

Based on this small-scale study, was the selected approach too ambitious? The variation between pupils and pupil groups was larger than that between schools, as teachers' observations and experiences in different schools were very similar. We suggest that this was mainly due to the projects representing learning tasks that were unfamiliar to the pupils. It is not only the subject-specific content but also the approach required by a specific type of learning task that needs to be taught to pupils. Furthermore, some teachers reported that many pupils unfamiliar with these pedagogical practices resisted leaving traditional craft content behind. However, a clear majority of these teachers are committed to continuing to develop their teaching practices along the lines of a non-linear maker pedagogy. Braskén et al. (2019, p.14) call for 'a clearly articulated, theoretically founded rationale for how to plan and deliver the curriculum in a way that engages students'. In our view, a non-linear maker pedagogy is a suitable vehicle for the change towards teaching 21st-century skills. Participatory methods, such as research–practice partnerships (Coburn & Penuel, 2016), have allowed us to involve more teacher practitioners (initially unfamiliar with the maker technologies and principles of a non-linear pedagogy) in the numerous maker projects we have initiated. For non-linear co-teaching of transversal skills and novel technologies, the principle is the same as for pupils' non-linear learning projects; rather than being right or wrong, solutions are either functional or in need of further development and testing. In this valuable development work, teachers deserve more support than is currently available for them.

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