Three approaches to multi-materiality through co-taught learning projects

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This study examines the implementation of multi-material crafts in Finnish basic education from the viewpoint of utilizing co-teaching to enhance craft education. With the removal of gender-segregated craft subjects and the merger of textile and technical subjects into a common craft subject, room for new pedagogical strategies has emerged. The study involved 17 teachers who had participated in a national development program aimed at integrating multi-material and co-teaching methods into the learning process in crafts. Data were collected through interviews, focusing on how these teachers planned and executed multi-material craft projects in a co-teaching setup. The results showed that teachers adopted diverse approaches to multi-material crafts, depending on their pedagogical aims and the resources available. Three major categories of multi-material, co-taught learning projects were identified – fixed, teacher-directed, and open choice – each offering varying degrees of material and technological integration and pedagogical freedom. The study also found that newly acquired technological skills significantly influenced the roles and collaboration dynamics between co-teachers, positively affecting the division of labor and the overall teaching and learning experience.

Keywords: co-teaching, craft teaching, multi-material crafts, material technologies, co-regulation

TECHNE SERIES

Techne Series 31(3), 2024
Pages: 16–32

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https://doi.org/10.7577/TechneA.5921

Introduction

Teaching crafts in basic education is evolving. During the last decade, teaching crafts has been influenced both pedagogically and content-wise by international trends, such as maker pedagogy (Blikstein & Worsley, 2016; Härkki et al., 2023) and design thinking (Borg et al., 2021; Goldman & Kabayadondo, 2016; Grönman & Lindfors, 2021). In Finland, a discussion on teaching crafts began after the 2016 enactment of the national core curriculum for basic education (NCC) (Kokko et al., 2020). In this NCC, "the task of the subject crafts is to guide the pupils to manage a complete crafts process. Crafts is a subject in which multiple materials are used, and its activities are based on craft expression, design and technology" (Finnish National Board of Education [FNBE], 2014, pp.155). At the level of the subject, common crafts includes both technical work and textile work (Pöllänen et al., 2021; Porko-Hudd et al., 2018). However, no instructions to use particular pedagogical models, technologies, techniques or materials in crafts teaching are provided, and no instructions at the level of individual learning tasks or projects are provided by the NCC (Pöllänen, 2020; Pöllänen et al., 2021). This leaves considerable freedom to teachers to plan and implement multi-materiality - individually or together through co-teaching. Moreover, previously separate textile and technical work teacher training programs at universities were transformed into programs providing one qualification: a craft teacher. This has raised concerns about the future employment market and the role of textile and technical work teachers, a worry shared by students and in-service teachers.

Alongside the NCC change, the emphasis was placed on three-dimensional (3D) printing, laser cutting, wearable technologies with a variety of sensors, as well as computational thinking, coding, and robotics—techniques that did not traditionally belong to the subject of crafts. In addition to this digital content, a national-level development program, Innokomp, introduced co-teaching and design-based pedagogical models for in-service teachers (https://blogit.utu.fi/innokomp/en/home/). While discussions around the subject of crafts persist, teachers' choices as enacted in schools on a daily basis could have profound implications for pupils' craft-related skills and attitudes, as well as the development of personal and social qualities (Hartvik & Porko-Hudd, 2023). Pöllänen (2020) and Pöllänen et al. (2021) discuss pedagogical solutions for implementing multi-material crafts in basic education. However, there is currently a paucity of research-based pedagogical approaches for multi-material crafts, especially of those variants that capitalize on possibilities for co-teaching that cross the divide between textile and technical material technologies. Hereon, multi-material crafts refer to the subject of crafts in Finnish basic education, while material technologies refer to both traditional crafts, such as woodworking and textile techniques, as well as digital modeling and manufacturing techniques (Jaatinen & Lindfors, 2016).

From these premises, this pedagogical research aims to widen perspectives on multi-material crafts by describing various types of learning projects that introduced multi-materiality through co-teachers' expertise covering a multitude of material technologies. We studied the teaching of multi-material crafts by teachers who participated in the above-mentioned in-service training after the 2016 NCC enactment. Specifically, we set two research questions:

RQ1: What types of multi-material craft-learning projects did teachers plan and co-teach?

RQ2: How did newly learned technologies influence co-teachers' roles and the division of labor?

We begin by introducing crafts as an evolving Finnish school subject and its versatile learning environments. The relevance of co-teaching as one possible pedagogical solution for multi-material crafts is first approached by introducing co-teaching as presented by international research and then as Finnish practice with its particular history, followed by two craft-specific co-teaching models. Through empirical data, we describe the types of pedagogical solutions for multi-material crafts (i.e., multi-material learning projects) that teachers planned and implemented. Furthermore, we describe how teachers' newly learned technological skills affected teachers' roles and the division of labor in multi-material learning projects. Finally, we discuss future possibilities for co-taught multi-material crafts.

Crafts as a unique, evolving school subject

The craft subject has many unique qualities. Hartvik and Porko-Hudd (2023) used knitting a sock as an example to describe the manifold learning taking place, even in low-technology tasks. Their model divides learning resulting from a craft process into medium-specific and medium-neutral learning. Unique subject content, knowledge, and skills for planning and targeted work activity are accompanied by diverse competencies, capabilities, and attitudes derived from the subject (Hartvik & Porko-Hudd, 2023). This combination provides versatile learning opportunities by connecting socio-material learning to bodily processes. Crafts can be rewarding, but also require perseverance, as successes and failures are (often all too) tangible. Among other things, crafts provide opportunities for pupils to develop their capacity to manage life situations in a constructive way (Hartvik & Porko-Hudd, 2023). This comes at a cost: Teachers' pedagogical choices should be based on an overarching and versatile understanding of what can—and should, according to the NCC—be achieved during craft lessons.

Finnish crafts is a compulsory subject for grade 1–7 pupils, and for grades 8–9, schools can offer crafts as an elective subject (Pöllänen, 2020). The current NCC (FNBE, 2014) on crafts includes learning objectives, such as designing and manufacturing craft products by utilizing varied materials, tools, and

techniques responsibly, safely, and purposefully, mastering holistic craft processes, as well as persevering and working responsibly. In addition, setting one's own learning objectives, trusting in one's own capabilities, creating aesthetic and technical solutions, and evaluating one's own learning are included. However, over the last few decades, the various NCCs have evolved in several dimensions. Probably the largest change, retreating from the gender-segregated character of crafts, began in the 1970s along with the introduction of comprehensive schooling. It was (likely) completed by the NCC enacted in 2016 (Kokko et al., 2020), when the option provided by the 2000s' NCCs for schools and school districts to allow grade 5–9 pupils to specialize in one or another content area, based on pupils' interests, was eliminated. Nevertheless, even in present-day crafts, pupils are often taught by two different teachers with different expertise: within one subject, there are two different specializations.

Another significant change concerns the NCC's role in specifying what is actually taught. The NCCs of the 1970s and 1980s specified craft techniques, materials, and even products to be made by pupils at a detailed level (FNBE, 1970, 1985). In contrast, three of the latest NCC editions (FNBE, 1994, 2004, 2014) have abandoned these listings of craft technologies and materials. Instead, these curricula have provided a flexible framework for introducing various craft materials and crafting methods to pupils (Porko-Hudd et al., 2018). The 2004 NCC emphasized focusing on the central materials, tools, and methods of textile craft and technical work (FNBE, 2004). Along similar lines, the current NCC instructs to "unprejudiced implementation of various visual, material, technical and manufacturing solutions", "understanding, evaluation and developing of various technological solutions" and "enforcing of premises for versatile work" (FNBE, 2014, pp. 155). This has left individual craft teachers with considerable freedom—and responsibility. Furthermore, the change in lesson hour distribution—that is, where the emphasis shifted from upper grades 5–7 to the lower grades—together with a lack of practical guidance has resulted in some teachers perceiving the current NCC and its enactment as vague and somehow elusive (Kokko et al., 2020).

A detail that has been discussed is the role of design in crafts. The 1990's NCC (FNBE, 1994) introduced the idea of holistic craft, and the actual concept emerged in the 2000's NCC (FNBE, 2004). Holistic craft (Kojonkoski-Rännäli, 1995) in the NCC refers to pupils engaging in iterative craft processes: idea creation and further development, aesthetic and technical planning, as well as making the artifact. Importantly, during all these phases, pupils engage in self- and peer-evaluations (Pöllänen, 2009; Porko-Hudd et al., 2018). The current NCC emphasizes mastering the holistic craft process, and views crafts as an activity based on craft expression, design, and technology, which includes investigative, inventive, and experimental activities (FNBE, 2014). Thus, design has belonged to craft curricula for the last 30 years.

Crafts require multiple learning environments

Various phases and techniques relevant to crafts set high expectations for learning environments. The holistic craft process begins with brainstorming, followed by experimentation with 2D sketches and 3D models, either individually or in groups (Härkki et al., 2018; Lahti et al., 2016). As making progresses, a variety of materials are processed using tools, machines, and equipment suitable for each material (Jaatinen & Lindfors, 2019). Rather than residing within the walls of a single classroom, hands-on activities take place in schools' various craft-learning environments, which include specially designed spaces for different material technologies (Käsityön oppimis- ja työympäristön suunnitteluopas [KOTS], 2024), workplaces, and workstations.

Workplaces (places where pupils work) and workstations (locations in which a machine or device is safely positioned; Lindfors et al., 2016) have different design criteria. For practical reasons (dust, noise, heat, etc.), technical and textile techniques have dedicated spaces, one ruled by a teacher with technical work qualifications, and the other ruled by a teacher with textile craft qualifications. Traditionally, these

two spaces are located far from each other within school buildings, which presents challenges for teacher cooperation and a variant of multi-materiality that aims crossing the divide between material technologies (Kokko et al., 2020; Lindfors et al., 2021). Nowadays, in some school buildings, technical and textile spaces are closer together (KOTS, 2024). Technical workstations are dedicated to activities such as woodworking, machining, metalworking, plastics, finishing, heat treatment, storage, computer-aided design, robotics, and electronics. Textile craft spaces often resemble studios and comprise stations for sewing, overlocking, knitting, weaving, printing, dyeing, and integrating electronics into textiles (KOTS, 2024). Furthermore, spaces for digital technologies, such as 3D printers and laser cutters, are required (Jaatinen et al., 2019). To conclude, the characteristics of craft-learning environments and, consequently, the characteristics of craft teaching differ profoundly from most school subjects—especially from subjects such as literacy, mathematics, and second languages, which have traditionally utilized co-teaching.

Co-teaching as described by international research

Frequently, co-teaching definitions emphasize teacher collaboration throughout the phases of planning, teaching, and evaluation (e.g., Thousand et al., 2006), and often link co-teaching to collaboration between a special education teacher and a class or subject teacher (e.g., Friend et al., 1993; Pulkkinen & Rytivaara, 2015; Saloviita & Takala, 2010). Co-teaching has been linked to addressing the diversity of pupils, delivering quality instruction, facilitating positive learning processes (Fluijt et al., 2016; Friend, 2016), and to teacher professional development (Rytivaara et al., 2024).

Since the 1950s in the USA, a multitude of co-teaching research has focused on special education. At first, co-teaching was a solution to teacher shortages and to fulfilling the educational needs of an increasingly diverse student population (Friend et al., 1993). In 1960s' England, a movement toward student-centered teaching was powered by co-teaching, and simultaneously, co-teaching implementations spread to various countries (Friend et al., 1993). Global momentum for co-teaching was built by the UNESCO 1994 declaration, which created a strong link between the notion of "co-teaching" and special education. Thus, two branches of international co-teaching research can be identified. Primarily, the focus has been on a special education teacher collaborating with a classroom teacher, aiming to provide scaffolding tailored according to each pupil's needs (e.g., Fluijt, 2017; Friend, 2016; Hackett et al., 2019; see also a review by Nápoles, 2024). The other branch (e.g., Kodkanon et al., 2018; Murata, 2002) examines co-teaching between subject teachers from different disciplines in post-primary education (equivalent to Finnish upper secondary or tertiary education). Even though co-teaching has spread globally and across various subjects and disciplines, very little research has described co-teaching in arts, crafts, design, or technology education. Due to this focus, *international research provides little pedagogical guidance that can be readily adopted by craft teachers.*

Co-teaching research has provided several typologies and developmental models, as well as contextualizations and system models. The most influential typologies focus on co-teachers' division of labor and the grouping of pupils (e.g., Friend et al., 1993; Thousand et al., 2006). In these typologies, teachers' roles vary from assisting or complementary activities to teaching as peers with equal status. Here, equal status translates into both (all) co-teachers being involved in all three phases of teaching: planning, classroom implementation, and assessment of pupil learning. An example of a typology based on learning objectives and pedagogical approaches is found in Wenger and Hornyak's (1999) study. They separate sequential, distinction-based, and dialectic co-teaching, as they assume that different types of teacher interaction facilitate different levels of student learning and the acquisition of epistemic practices. The distinction here is that typologies provide a snapshot that describes co-teaching as static, while developmental models suggest that co-teaching is a professional, intentionally built partnership that develops through several stages as the partnership matures (Gately & Gately, 2001; Pratt, 2014;

Rytivaara et al., 2019). Typical of these models are qualitative changes in communication, commitment, and mutual trust, all of which are valuable cornerstones of co-teaching partnerships.

However, co-teaching is not merely a tango for two or only for teachers. While successful co-teaching relationships and implementations share certain qualities and shared practices, research from early on has emphasized the criticality of support (Cook & Friend, 1995; Saloviita & Takala, 2010**)** and opportunities for in-service training and professional development (for a review, see Rytivaara et al., 2024). Contextualized (Härkki et al., 2021) and systemic models (Hackett et al., 2019, 2021) consider factors external to the pair (or team) of co-teachers in more detail. External factors include educational policy and the national core curriculum, school community, and administration (Härkki et al., 2021); thus, success in one subject or in one school does not guarantee success in other subjects or schools. Other external factors of note include local features interacting with the learning environment, such as the rationale for instituting co-teaching, and the norms, responsibilities, views of instructional change, and shared tools to enable the successful implementation of co-teaching (Hackett et al., 2019, 2021). Thus, teacher-level commitment is insufficient for successful co-teaching implementation.

Finnish perspective on co-teaching

In Finland, the roots of co-teaching can be traced to inclusive practices. However, the concept originally used in Finland for co-teaching emphasizes teachers' simultaneous presence rather than collaboration, an image that persists.

NCC equates "co" with simultaneous

During the 1970 educational reform (the transition from primary schools to comprehensive schools), the NCC introduced co-teaching (Saloviita, 2016). The word used then, and also in the latest NCC, is *samanaikaisopetus*, for which the literal translation is "simultaneous teaching." In the 1970's NCC, simultaneous teaching entailed cooperation between special and mainstream teaching (FNBE, 1970). In the current NCC (FNBE, 2014), simultaneous teaching is linked to special education, with intensified and special support for learning. The literal translation of "co-teaching," in Finnish, *yhteisopetus*, is not in the NCC's vocabulary. *This separation of concepts appears noteworthy*.

Despite the absence of "co-teaching" in the current NCC, teacher *cooperation* has received a mention: "Adult cooperation, such as simultaneous teaching, provides a model of school as a learning community also for pupils. Cooperation is required, especially in planning and implementing interdisciplinary learning modules, in [the] assessment and support of learning, as well as in [the] implementation of student welfare services" (FNBE, 2014, p. 36). Thus, the idea of co-teaching is present, even if the word remains absent.

Nevertheless, the word co-teaching (*yhteisopetus*) is regularly used in speech and other documents. Finnish-language research (e.g., Ahtiainen et al., 2011; Malinen & Palmu, 2017) and literature directed at teachers (e.g., Saloviita, 2016) is primarily focused on simultaneous teaching in theoretical subjects and tends to use these words interchangeably. However, from the viewpoint of crafts, the separation of *co*-teaching and *simultaneous* teaching is a necessity, as the typical configuration of craft-learning environments counters teachers' simultaneous presence within one space. For the purposes of crafts, co-teaching needs to be characterized by other qualities.

Co-teaching in Finnish crafts

Co-teaching the subject of crafts has four distinct characteristics. First, teachers' co-presence is replaced by each teacher teaching within his/her own (either textile or technical work-oriented) space, respective to their craft expertise (Krapi et al., 2019). Rather than seeing each other, they remain visually (often also physically) isolated. From this condition stems the second characteristic. The size of the pupil group per teacher remains the same in co-teaching as in solo teaching. This is a significant difference from

mainstream co-teaching, in which the pupil–teacher ratio is halved when two teachers cooperate. Third, no status imbalance (as is often noted in international research) exists between teachers. Textile teachers and technical work teachers are equal experts in their own domains. Therefore, the above-mentioned co-teaching typologies based on a division of labor (e.g., Friend et al., 1993; Thousand et al., 2006), where one teacher assists or complements the other, are unhelpful and even damaging. This brings us to the fourth characteristic. At best, co-taught crafts combine teachers' diverse expertise and strengths within learning projects that explicitly require crossing the divide between textile crafts and technical work and purposefully utilizing various materials and techniques (Jaatinen & Lindfors, 2016).

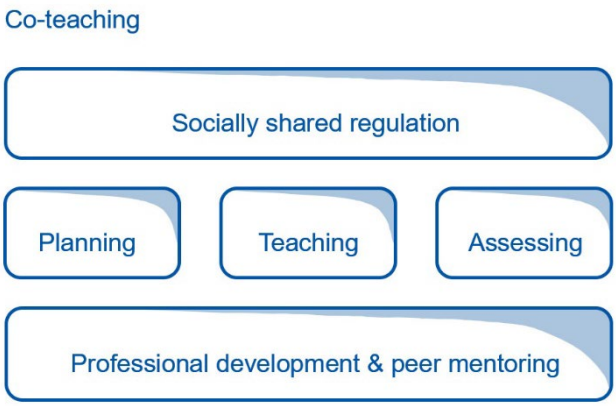
Two models of co-teaching Finnish crafts have been identified: a developmental model (Jaatinen & Lindfors, 2016; Krapi et al., 2019) and a typology (Härkki et al., 2021). Both models stem from contexts in which the above-mentioned characteristics are realized. However, a contextual difference exists, as the developmental model studied crafts taught in learning environments specifically designed for multi-material crafts.

The first model (Jaatinen & Lindfors, 2016; Krapi et al., 2019) comprises three developmental stages: emergent, evolving, and proficient co-teaching. What is notable in this model is the change in learning projects planned by co-teachers. The emergent stage involved teachers setting no constraints on pupils' projects, but the higher the stage, the more constrained the learning projects became. Similarly, cooperation between material technologies increased, and burdensome feelings changed into sharing ideas, values, and pedagogical practices. Furthermore, pupil assessment becomes more reasoned, equitable, and balanced between technologies. Proficient co-teachers planned motivating and well-defined learning projects, and they trusted each other.

The other model (Härkki et al., 2021) also comprises three categories: highly functioning co-teaching, collaboration, and imbalanced co-teaching. These categories are not considered a developmental continuum. Balance refers to sharing the workload and responsibilities. In imbalanced co-teaching, one teacher planned and was responsible for the whole plan–teach–assess cycle, while the other teacher participated in implementing the plan (via classroom teaching). On the other end, highly functioning co-teaching was characterized as teachers having mutual trust, resilience, a commitment to developing co-teaching practices, and shared values. More importantly, teachers engaged in the socially shared regulation [SRR] of their work. SRR is a reflective and action-oriented practice (cf. Järvelä & Hadwin, 2013) that continues throughout the whole plan–teach–assess cycle and in which teachers jointly decide on pedagogic objectives and practices. SRR also provides a platform for teacher professional development and peer mentoring.

Figure 1.

Socially shared regulation in highly functioning co-teaching, adopted from Härkki et al. (2021).



Co-teaching crafts is an option, not an imperative. Moreover, co-teaching is not synonymous with sacrificing (Finnish high) teacher autonomy (Saloviita & Takala, 2010; Webb et al., 2004) or one's values and pedagogical priorities. Instead, different viewpoints stage opportunities to learn and widen one's perspective (Rytivaara & Kershner, 2012). When teachers allocate tasks based on their strengths, their sense of achievement is enhanced, which in turn increases job satisfaction and well-being at work (Härkki et al., 2022; Krapi et al., 2019; Pöllänen et al., 2021). To conclude, co-teaching provides a possibility for professional growth through pedagogically trained professionals sharing and co-reflecting on their practice. However, it requires time, effort, and a willingness to give and accept feedback, not to mention the courage to step into the position of a learner in front of and together with one's co-teaching partner.

Method

Study context

The study was conducted as part of a development project initiated by the Ministry of Education and Culture to support craft teachers in enacting the NCC, published in 2014. A central mode of operation for the project was to develop pedagogical practices suitable for multi-material crafts in collaboration with in-service teachers. To achieve this, the project provided training to in-service teachers in multi-materiality and novel material technologies, such as 3D printing, laser cutting, and robotics, as well as in co-teaching. Furthermore, several pedagogical models suitable for basic education invention and design projects were introduced to the teachers. This arrangement intended to recognize that learning task design is affected also from several teacher-independent situational factors as well schools-specific pedagogical features and learning environments.

Study participants and data acquisition

The study participants included teachers from partner schools in eastern and southern Finland. Teachers gave their informed consent to participate and were interviewed for this explorative study. Purposeful sampling (Palinkas et al., 2015) was utilized with the following criteria: the teachers had co-taught and implemented multi-material learning projects with their pupils (1–3 per co-teaching team) during Innokomp. All the teachers had planned the learning projects themselves. The learning projects varied in duration (2–5 months), in pupils' grades (1–8), and in the number of classes participating (1–4). Geographically, the schools were located within quite a wide area, from city centers to rural areas. The teachers' experience in co-teaching varied from several years to none, as one pair had not collaborated before. After the first year, two teachers resigned, and new teachers were hired. Thus, two pairs started from beginning on year two. Therefore, we believe that this sample of seventeen teachers (8 pairs and one team of three) provided a reasonable variation.

The interviews were conducted at the end of the co-taught learning projects in a time and place chosen by the teachers. An interview protocol for semi-structured group interviews (Kallio et al., 2016) was developed to ensure comparability among teams (Barribal & White, 1994). Internal testing of the protocol (Barriball & White, 1994) was conducted by fellow researchers involved in the project, and adjustments were made based on their feedback. The interview questions concerned the planning of learning projects, the division of labor, whether co-teaching changed teachers' experiences of teaching, their roles in multi-material crafts, and shared reflection. However, the teachers were given considerable freedom to raise topics that they felt were relevant, as the group interviews had a two-fold aim: to collect research data and, more importantly, to offer teachers the opportunity to enhance their co-teaching skills by reflecting on their teaching experiences and cooperation (Fluijt et al., 2016). As the interviewers were

familiar with the teachers from the project's training days, the interview situations were rather informal, with teachers sharing their concerns, joys, and challenges quite openly. Altogether, five hours of audio data were acquired and transcribed verbatim.

Data analysis

Inductive qualitative content analysis (Zhang & Wildermuth, 2009) and Atlas.ti software were utilized for data analysis. Initially, the transcripts were thoroughly read multiple times to gain a comprehensive understanding of the diverse ways in which the teachers addressed the issues. Through careful examination and a comparison of inferences, a categorization scheme began to materialize, and a theme was selected as the unit of analysis. We wanted to avoid orienting toward individual craft products and techniques—that is, dimensions absent in the NCC—as we thought that would provide case descriptions of multi-material products rather than generalizable research results on multi-material craft pedagogy. Keeping the analytical focus on learning project features and pedagogical choices, such as pupils' possibilities to choose (materials, techniques, aesthetic details, etc.), material-technological and design constraints set by teachers, and whether pupils worked individually or in pairs, forming themes became relatively straightforward. Most often, a theme comprised several sentences expressing an idea or describing an issue. Related to the first research question, a typical theme included the teacher's (often fragmented) description of how materials were selected for projects, who made the choices, and how pupils interacted with the materials. For the second research question, a theme described teachers' roles and responsibilities, which they typically expressed in a rather concise way.

The analysis was conducted by the first and second authors of the article. The data-driven categorization scheme and related data examples are presented in the results chapter. In the data examples, the teachers are referred to using pseudonyms rather than their actual names.

Results

Research question 1: What types of multi-material craft-learning projects did teachers plan and co-teach?

Teachers had full freedom to plan learning projects and define multi-materiality that they felt was appropriate for their pupils, learning environments, and budgets. Following the disposition of the current NCC, our analysis did not focus on specific materials or technologies. Rather, we analyzed pedagogical arrangements (types of learning assignments and pedagogical approaches) and the ways in which teachers defined multi-materiality for the assignments. Three major categories of multi-material, co-taught learning projects were identified: fixed, teacher-directed, and open choice. For projects involving fixed material technologies, teachers decided beforehand which materials and material technologies pupils could apply. In addition, the projects were also teacher-led. For teacher-directed multi-materiality projects, teachers decided beforehand which materials or material technologies pupils could choose from. These projects could be either teacher-led or learner-centered. In open-choice learning projects, teachers planned open-ended learning assignments and facilitated pupils' ideas and planning. Pupils could choose materials and material technologies (see Table 1). Table 1 provides more detailed descriptions, accompanied by data examples.

Table 1.

Categorization for co-taught learning projects implementing multi-material crafts

Category	Multi-materiality in co-taught learning projects	
M—I	Fixed material technologies: Teachers decide on materials/material technologies per learning project	
	M—Ia	Teacher-led learning project, traditional craft techniques and content
	M—Ib	Teacher-led learning project, traditional craft content seasoned with new material technologies
M— II	Teacher-directed multi-materiality: Pupils are given some freedom to choose, within limits	
	M—IIa	Teachers decide on a variety of materials/material technologies for pupils to pick from
	M—IIb	Teachers decide on one material/material technology and pupils choose other materials/material technologies
M—III	Open choice: Teachers plan an open learning assignment and facilitate pupils' learning activities, pupils choose materials/material technologies	
	M—IIIa	Open assignment, pupils' choices are unlimited
	M— IIIb	Open assignment, pupils can choose within limits

Projects with fixed material technologies (category M–I) were teacher-led. Some of these were based on the traditional content of crafts (category M–Ia), such as a textile board based on a fairy tale:

> Vertti: 5th graders borrowed fairy tale books from the library and chose one tale or story. [...] Then they chose three or four highlights and turned those into pictures, textile art [...]. We told them to use four different techniques at every step of the process. Next [in small groups], pupils worked with those pictures.
>
> Mai: At some point, we divided the class so that some of the pupils continued with [woodwork] techniques. To design suitable frames [for their group's picture], and next, to produce the inner frame and outer frame that were then decorated according to their choices. (Vertti & Mai, 2019)

Some teacher-led projects combined elements traditionally used in craft teaching with new material technologies (category M–Ib). For example, in the Mollukka project, pupils used small 3D-printed components, such as eyes and mouths, for their wooden dolls.

> Frans: We have 3D-printed eyes and mouths and guitars, and whatnots using PLA plastic as a raw material. (Bertta & Frans, 2018)

Compared with category M–I teacher-led projects, pupils had more freedom in teacher-directed multi-materiality projects. Two subcategories were identified. In the first project subcategory (M–IIa), teachers chose alternative materials and material technologies from which the pupils could pick some. For instance, teachers defined how the theme of the project was the kitchen (e.g., utensils and textiles), or that pupils were to design a seat that also functioned as storage.

> Vertti: This seat, this is by all means not otherworldly, not a novel idea … make a seat of some kind during school crafts. But those seats enable, in a way, a vast number of possible variations. One can do it within that [assignment] and combine different materials appropriately and reasonably, without feeling that now you must force [an unsuitable combination]. In this [project], we required that [pupils] would somehow combine woodwork with textile crafts. And this project had to involve a storage solution, so had it been a mere seat, it wouldn't have been ... it had to include a storage function, too. (Vertti & Mai, 2018)

In the second project subcategory (M–IIb), teachers decided on one material or material technology, and pupils were permitted to choose other materials, as demonstrated in the car tire project:

> Noora: That scope and the idea we've had for a long time [is] that [the learning project] would somehow utilize car tires. (Noora & Tauno, 2018)

As we proceed with the category definitions, pupils' freedom to choose increases. The last category involved open-choice projects (category M–II), in which teachers planned open-ended assignments. These assignments followed the pedagogical principles of non-linear projects (Hakkarainen & Seitamaa-Hakkarainen, 2023). In these kinds of projects, teachers facilitate pupils' ideas and planning. Teachers are continuously challenged by the timely scaffolding of pupils' work and acknowledging their role as co-learners (Härkki et al., 2023). In some projects, the teachers did not clearly constrain pupils' work during the project design phase, but the pupils had (seemingly) unlimited possibilities to choose from (category M–IIIa). An example of such a project is My Space. According to the teachers, the learning assignment was unsuccessful. Too much freedom challenged pupils to make a series of choices independently, for which they were not ready. Much scaffolding was required, and the teachers were unprepared for this type of increased workload. Finally, the pupils' projects were left unfinished, as the pupils did not have the required material-technological skills. This was also a difficult experience for the teachers.

> Ilari: Our learning project was "My Space," so we had a problem-based start. Pupils decided which space from their own home, garage, [or] someplace where there was a problem that he wanted to solve. (Ilari, 2018)

Another subcategory (category M–IIIb) involved open-ended learning assignments with predefined constraints for the design and make phases. These constraints were imposed by teachers to avoid paper-based crafting and to ensure that pupils utilized the new material technologies that they had just learned. Still, an abundance of choices bothered many pupils in several of these projects, centering on the theme of an Everyday Challenge. Terms such as "manufacturing techniques" or "smart project" were utilized to outline constraints for the design and make phases, as exemplified in the following Everyday Challenge project:

> Kai: In this smart [learning] project, pupils were required to do some programming. I define that smartness, if there is a smart product [to be made], must include a programmable Adafruit component. When it has those sensors, the smartness means that it actually uses those sensors to [activate some effect]. That's the way to make use of the smart components. (Bea & Kai, 2019)

However, design constraints were not always incorporated effortlessly into pupils' projects. For instance, in one of the Everyday Challenge projects, which tasked the pupils to build "smartness" into their products, the pupils needed to be repeatedly reminded about this design constraint:

> Inkeri: All the pupils have studied basics, and some have some kind of semi-application ... there's some kind of code in their product. We have kind of forced them to, hey now, [make code] that some LED would light up. (Inkeri & Miia, 2019)

To sum up, teachers chose very different ways to implement multi-materialism, both in terms of technologies and pedagogical solutions. However, that was the original intention. In collaboration with teachers, they were to develop pedagogical solutions that they considered suitable for the conditions in their schools.

Research question 2: How did newly learned material technologies influence co-teachers' roles and the division of labor?

In the Innokomp project workshops, the teachers were introduced to new material technologies, such as 3D-printing, laser cutting, programming, robotics, and e-textiles. The teachers could freely choose which ones to learn. While some teachers were complete novices, others had prior experience with one or two of these technologies. In any case, for all the teachers, much remained to be learned. Later, when teachers planned multi-material learning projects for their own pupils, they were free to choose how to organize their co-teaching roles and responsibilities.

In the interview data, three categories characterizing teachers' choices for a division of labor could be identified (Table 2). The key issue was whether one or both teachers assumed (or could assume) the role of an authority regarding a specific material technology and related equipment.

Table 2.

Categorization: Teachers' roles and the division of responsibilities

Category	Roles and the division of labor regarding new material technologies	
R–I	Equal authority, equally shared responsibilities	
R–II	Fixed authority and a division of responsibilities	
	R–IIa	Location-based: Determined by equipment placement (textile or technical space)
	R–IIb	As pre-negotiated and agreed, based on previously acquired competence or topical interests
R–III	Advanced co-teaching: Authority and the division of responsibilities varied flexibly, according to situational needs	

In most co-taught learning projects, both teachers were equally involved in teaching new material technologies (category R–I). Both teachers had participated in training sessions, acquired new knowledge, and were motivated to practice. Despite the typical organization of craft-learning environments, and the fact that the class was divided in two to work in separate spaces (which is a typical way to organize craft co-teaching), the teachers managed to share responsibilities equally. For example, one of the teachers in the Everyday Challenge described how coding with Circuit Playground was organized, despite the teachers operating in two different workshops:

> Miia: In a way, we had the same plan.
>
> Inkeri: The same plan and the same goals. (Inkeri & Miia, 2019)

Sometimes, one of the teachers took more responsibility for new material technologies. This could be due to the location of the necessary equipment, such as computers or 3D printers (category R–IIa).

> Bea: Then again, you had the computers too [in your workspace]. It's true that when we need a computer, we had to go where there were laptops, as I don't have any laptops [in my workspace]. I only have iPads. (Bea & Kai, 2019)

When the physical learning environment (dedicated workspaces, equipment placement, etc.) was rigid and difficult to change, the teacher who had the computers (or other special equipment) also had authority and the main responsibility for their use. These roles were fixed. When the physical learning environment (or teacher territoriality) did not dictate the roles, the teachers had the opportunity to negotiate and agree on responsibilities more flexibly. One teacher could have acquired the necessary competence (and maybe also applied it in his/her teaching) previously (category R–IIb):

> Bea: I think pretty much the responsibility [for teaching programming] was with you. Then, there were only a few things to sew, some LEDs, which I taught.
>
> Kai: A few years ago, I taught an elective IT course. (Bea & Kai, 2019)

For these teachers, it felt natural that the more skilled one took on the teaching responsibility. At times, the teachers agreed on roles and responsibilities while planning the learning project:

> Bettina: [When we have] taught together, we have agreed that you'll have the responsibility for this, and I'll have the responsibility for that, and we both help each other. It has worked out [fine], just like that. (Bettina & Benjamin, 2018)

> Jaana: In a way, the planning phase, and acquisition of materials, that's something we always share and discuss, [whether] I go, or you go... (Jaana & Lenita, 2018)

The third identified way of deciding on roles and responsibilities was related to the quality of collaboration between the teachers. An advanced stage of co-teaching is characterized by teachers acting flexibly according to situational needs (category R–III). When collaboration reaches this stage, teachers find it unnecessary to agree on specific responsibilities or divisions of labor beforehand.

> Netta: It feels natural; the responsibility for teaching is no more yours than it's mine.
>
> Anna: Even though at times we repeat the same things [too].
>
> Netta: It's good that we repeat; that's best for them. They'll hear things at least at some point, even if they don't hear it the first time.
>
> Annika: That's what I'm thinking here. We do that during classes also. We always start and discuss things. On the other hand, it's good to show the pupils [our way of working], the two of us here discussing, at least in some classes. We have planned together how to proceed, but then we always change [the lesson structure] together on the fly. (Netta, Anna, & Annika, 2019)

In any case, teachers need to decide, either implicitly or explicitly, beforehand or on the fly, whether they will share or divide technology-related tasks and roles.

Discussion and conclusions

This research identified pedagogical approaches that are not restricted to specific material technologies. Instead, they can be adapted and adopted to various material–technological combinations. These research-based approaches arise from the teachers' own preferences and planned implementations. While we expect other categories and categorizations to emerge by subsequent research and by teachers' practical work, we believe that the delineation based on our data offers guidance for teacher training and a pragmatic approach to co-teaching in schools, thereby reducing the hesitation felt by teachers in adopting the curriculum. These approaches can be applied by individual teachers, as well as by pairs or teams of co-teachers. However, we see that the wider the material-technological expertise of the co-teaching team, the higher the possibility is for pupils to choose exciting and authentic learning projects.

This study has some limitations. Teachers having the privilege to participate a development program such as Innokomp face a different situation and are provided more support than teachers in the field. Simultaneously, the participating teachers had at least some level of interest towards co-teaching and mutual collaboration. This could have had implications on the learning projects they designed. Classroom video data were available from some schools but not utilized in this study. Due to most learning projects taking entire spring semester and located in different schools, organizing video observations that would provide a secure base for data triangulation (interviews and video data) proved beyond the limits of the program. In the future, valuable information could be achieved by a wider study on multi-material crafts teaching. Ideally, that research could cover pedagogical approaches, involved technologies and materials, and possible co-teaching related features of the implemented learning projects. Important topics for further research include also restrictions imposed on teaching multi-material crafts by learning environment and other teacher-independent factors.

Earlier studies (Jaatinen & Lindfors, 2016; Krapi et al., 2019) have highlighted the promotion of co-teaching as a possible solution for multi-materiality. Our results emphasize the critical role of material-technological and design constraints to be set on pupils' projects. Earlier research linked projects with no teacher-specified constraints to emerging co-teaching rather than to more evolved collaboration (Jaatinen & Lindfors, 2016) and recognized that open tasks and knowledge demands defined by pupils' projects (rather than teachers' predefined agendas) require teachers to carefully observe when pupils need scaffolding (Härkki et al., 2023). In the multi-material learning projects of our data, teachers' expertise was typically well capitalized, and the newly learned material technologies offered a flexible

chance to plan learning projects to divide teachers' labor more equitably. Most often, pragmatism prevailed. Indeed, pragmatism is an excellent foundation for co-teaching. Overall, successful co-teaching emerged as a shared orchestration of pupils' work and learning, building on shared rather than on individual capacities (Härkki et al., 2023). These capacities include socially distributed metacognition and SSR, as well as collaboratively building a socio-cognitive learning infrastructure that facilitates meaningful participation and learning for all pupils. These translate into individually embedded and embodied classroom practices that co-teachers flexibly develop into socially and materially distributed activities that are suitable for both of them. The underlying principles involve equality, mutual respect and trust, a shared responsibility for outcomes, shared resources, and a shared vision. However, success in co-teaching depends not only on teachers but also on support from, for instance, the school community, as mentioned above (further elaboration is available in Härkki et al., 2021). Notably, successful implementations of co-teaching could improve the well-being of teachers (especially in the long term), as successes and other experiences can be shared with each other.

Prior research by Kokko and others (2020) highlighted three concerns regarding crafts: the implementation of multi-materiality, sufficient teaching hours, and the nexus between technology education and crafts. Indeed, multi-materiality has had various interpretations. On the one hand, many craft products represent purposeful combinations of materials (Hilmola, 2023). Conversely, combining techniques and materials from both sides of the previously gendered divide between textile and technical work is not typical of craft-learning projects. What proportion of all learning projects should be like this is a something that the teachers can choose to suit their situation, especially in the midst of the pressures of diminished teaching hours. In the end, craft teaching should follow the points set forth by the NCC and ensure that all specified learning targets are covered. Over the decades, curricula have slowly shifted emphasis from craft-making and certain products and techniques (i.e., unique subject content and subject-specific skills and knowledge) to a more holistic craft process and generic skills. This kind of pedagogy balances medium-specific learning related to a craft process with medium-neutral learning resulting from craft processes (cf. Hartvik & Porko-Hudd, 2023).

Currently, the teaching approach with the most potential for future-proofing craft teaching could be co-teaching. Co-teaching provides a tri-fold chance for craft pedagogy. First, it can generate interest in pupils regarding authentic craft projects that they experience as personally meaningful and that purposefully combine a variety of textile, technical, and digital techniques (Härkki et al., 2023; Jaatinen & Lindfors, 2016; Krapi et al., 2019; Pöllänen et al., 2021). Second, it can provide pupils with future skills learned through new material technologies combined with traditional craft techniques. This could, at best, culminate in a broad understanding of the limits of purposeful use cases—that is, which combinations of materials and techniques deliver the best solutions for each purpose—and which combinations are not worth trying. Third, it can provide teachers with mutual opportunities for continuous learning through professional interaction (Rytivaara & Kershner, 2012; Strogilous et al., 2023). However, capitalizing on this opportunity necessitates that we should also approach co-teaching from the perspective of the subject of crafts' realities (such as learning environments and other situational factors) rather than simply copying practices originating from special education and founded in teachers' co-presence in the classroom. As pedagogical objectives, possibilities, and constraints are very different in the subject of crafts than in other school subjects, they should be accounted for when conceptualizing and implementing co-teaching in crafts. *Due to the present-day pressures of rapid technological development, pupils' literacy and numeracy challenges, as well as ecological, ethical, and humanitarian issues, the subject of crafts could have a far-reaching impact on pupils' future skills—if we choose to continue strengthening the subject.*

Acknowledgements

This work was supported by The Ministry of Education and Culture, Finland [project Innokomp] and the Strategic Research Council of the Academy of Finland [project Growing Mind, grant number 312527].

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