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Interdisciplinary craft designing and invention pedagogy in teacher education: student teachers creating smart textiles

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Abstract The paper discusses how a teaching approach, *interdisciplinary design and invention pedagogy*, affected primary school student teachers' learning outcomes through the craft design process in pre-service teacher education. This study applies developmental work research (Engeström in J Educ Work 14(1):133–156, 2001; Engeström in Yhteiskehittely ja vaihdon vyöhykkeet tutkijoiden ja elinkeinoelämän välillä 2013; Galison in Image & logic: a material culture of microphysics. The University of Chicago Press, Chicago, 1997; Gorman in Trading zones, interactional expertise and interdisciplinary collaboration 2005) that aims to develop educators' work involved here. To support a craft-designing process and making innovative artefacts, two disciplines—natural science (physics) and drama—as examples of interdisciplinarity were invited to contribute to the craft process. The craft course on 'smart textiles' was carried out in the spring of 2014 and 2015 at the University of Helsinki in pre-service primary teacher education. The aim of the crafts course was to get student teachers familiar with different dimensions of crafts (textile, design and technology), inquiry-based designing and an interdisciplinary teaching approach to be used in a primary school context. The craft task included working in small groups and designing smart textiles. Student teachers documented their designing and implementation processes through photos and videos using applications such as iMovie or Movie maker. In addition, participants wrote comprehensions of their projects in learning diaries. The data consist of student teachers' learning diaries (N = 17) and prototypes (N = 17), which are analysed by qualitative content analysis. As results, first, the paper presents some innovative artefacts that student teachers created. Second, it describes the learning that emerged in pedagogical thinking of student teachers related to the

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interdisciplinary designing process, including (1) four interdisciplinary contexts, (2) new pedagogic thinking and (3) change of attitude towards integrative teaching.

Keywords Interdisciplinary teaching · Smart textiles · Craft designing · Making · STEAM disciplines · Primary teacher education

Introduction

The broad range of pedagogic interpretations and interdisciplinary teaching applications have been presented in the international educational context (e.g., Bresler 1995; Wilson 1999; Drake and Burns 2004; Puurula 1999; Uusikylä and Atjonen 2005; Visanti 2007; Sarkar Arani 2008; Blikstein 2013a). Interdisciplinarity in teaching and learning has raised an active discussion, especially in Finland since the new national core curriculum for basic education (Finnish National Board of Education 2014) was established, which strongly requires that teachers have a holistic view in their teaching.

The aim of an interdisciplinary pedagogy is to deepen learning and teaching in order to acquire a more holistic picture of the complex phenomena of nature, society and real life (Karppinen et al. 2012, 2013; Kallunki et al. 2017; Dillon 2008; Viilo et al. 2011; Wilson 1999, p. 9; Blikstein 2013b). In the 1840s, William Whewell introduced inductive sciences and the concept 'consilience', which means 'linking of facts and fact-based theory across disciplines to create a common groundwork of explanation' (Wilson 1999, p. 9). The point is about the depth of understanding; the better the student perceives the whole picture in connection with other contexts or the surrounding world, the deeper the student understands the content to be taught or learned.

Unlike many countries, in Finland, crafts are still a vigorous school subject in basic education and alongside in teacher education, including textiles and technology. In Finnish basic school history, crafts used to be divided into two separate subjects—technical and textile work. In 1998, the national core curriculum for basic education suggested having tuition for common crafts, including both subjects, for all students. Currently in schools, the tradition is still strong to divide these two subjects. However, the new national guidelines for basic education (Finnish National Agency for Education 2014) strongly demand holistic crafts and exploitation of both subjects. The aim here is to find a meaningful topic that connects both contents of crafts, productively uses information and communications technology (ICT) and employs a new dimension of interdisciplinary pedagogy across disciplines as contra to traditional subject-based and individual-based learning. In Finnish basic school, invention pedagogy and product development in maker-culture has not been a familiar approach but is getting more attention.

Therefore, in this paper, a new approach, *interdisciplinary design and invention pedagogy*, is applied to pre-service teacher education and used on a course that integrated crafts, physics, drama and ICT, focusing on student teachers' learning outcomes. Drama and physics are chosen here as examples of cross-discipline pedagogy. This paper discusses how the interdisciplinary approach enriches the craft-designing process and student teachers' pedagogic thinking. Our new approach is based on the Learning by Collaborative Design (LCD) model by Seitamaa-Hakkarainen et al. (2010). The new approach of crafts includes elements of meaningful creation and innovation pedagogy. This approach (interdisciplinary design and invention pedagogy) has adopted aspects of project-based, inquiry-driven, problem-solving, and community-based education in the STEAM (science, technology, engineering, art and mathematics) disciplines (c.f. FabLearn labs/Stanford

University 2017; Pratt IMARI Lab/Pratt Institute 2017; Technology Lab/University of Borås 2017; Blikstein 2013a, b; Seitamaa-Hakkarainen et al. 2010; Siegel 2008; Sawyer 2014; Kangas 2014; Paavola and Hakkarainen 2014; Braund 2015; Papert and Harel 1991; Hill 1998, 1999; Papert 1996, 1997). Craft designing consists of producing artefacts by exploring, innovating, making prototypes and testing new ideas. In this study, a fundamental aim, parallel to interdisciplinarity, is to give examples of how teaching crafts, both in basic education and teacher education, could be expanded towards more innovations and making culture. Making culture in education derives from maker culture and maker movement, which engage do-it-yourself (DIY) and do-it-with-others (DIWO) techniques and processes to share resources and knowledge, work on projects, learn about technology, solve problems and build unique products (ELI 2013; Rosenfeld-Harverson and Sheridan 2014).

This study is based on an interdisciplinary course in teacher education, where the craft-designing process and creation of innovative artefacts (smart textiles) was enriched by ideas from physics and drama education. For example, Langkau et al. (2003) have successfully used theatre playing in technology learning in basic school in an interdisciplinary manner. The craft course was carried out in the spring of 2014 and 2015 at the University of Helsinki in pre-service primary teacher education. This case study accepts the challenges of Finland's new national curriculum for basic education (2014) by discovering ways to use an interdisciplinary teaching approach in crafts and discusses how to implement the approach in a way to enhance participants' holistic learning and also student teachers' future teaching skills. The main research questions are:

1. How does the interdisciplinary design and invention pedagogy in crafts develop student teachers' pedagogic thinking?
2. How can other disciplines enhance the crafts-designing process?

Interdisciplinary approach

An interdisciplinary approach denotes teaching where multiple disciplines are involved in problem solving to redefine problems outside of normal boundaries, connecting topics and themes and reaching solutions based on a new understanding of complex situations (Bresler 1995; Cantell 2015; Lipponen and Rönnholm 2016; Wilenius 2015). This includes gathering fragmented information on varied disciplines into a more holistic set (see e.g., Simola 1988; Wilson 1999, p. 9; Cantell 2015). The fragmentation of an individual's knowledge structure or the lack of a holistic view is a common problem in many learning activities. The individual often learns only narrow fragments or details without the ability or possibility to construct broader pictures. This kind of knowledge fragmentation poses a problem not only to the student but to the teacher as well.

One of the reasons for this fragmentation is the subject-based instruction in schools and in higher-level institutions, such as in teacher education at universities in Finland (see e.g., Rantala et al. 2010). On the one hand, subject-based instruction in teacher training ensures that the student teachers learn the core contents of subjects well, which is a basic condition for interdisciplinarity. Interestingly, although class teachers in Finnish primary schools teach almost all of the subjects themselves and would thus have an excellent opportunity to deliver teaching in a holistic way, searching for connections among different subjects is not included directly in the teacher education programme (Syllabus of Class Teacher Training

2014–2015). On the other hand, this kind of separation of subjects is an international phenomenon. For instance, Henderson (2001) states that in the United States the school subjects are regarded as core elements of the curriculum and as standards for the school, state and national systems. For school learning, the main model comes from the universities, and the basis of it is still comminuted. In the United States, Wilson (1999) has used the concept of consilience, which aims to seek 'out the convergent knowledge and ideas across the different disciplines as the modern academia pushes against the sharing of knowledge across disciplines.' Wilson adds that 'consilience would be the way, for example, to look at inductive cores and find what they share in common and then create a complete picture' (p. 9).

The interdisciplinary approach refers to learning themes across disciplines as well their relationship to the real-world phenomena and understanding their connections in a wider perspective (UNESCO 2013). A wider perspective of things is easier reached by connecting experiences of different people through discussions and utilise distributed expertise (Hill and Smith 2003). This is a basis for constructivist and socio-constructivist views, primarily derived from the work of Piaget (1932) and thoughts of Lev Vygotsky (1931/1997). Further on, today's making-based pedagogy in crafts lays much emphasis on John Dewey's 'learning by doing' and Seymour Papert's 'learning by making' practices and underlines collaboration and project-based and inquiry-driven education, especially in the STEAM disciplines (e.g., Blikstein 2013a; Osborne and Dillon 2008; Viilo et al. 2011). Learning is an active process where people construct their own understanding and knowledge of the world through experiencing things and reflecting on those experiences (Vygotsky 1978; Papert and Harel 1991) over discipline borders. This means that learning is a personal interpretation of the world and is based on the person's prior knowledge.

In this study, interdisciplinarity is a pedagogic core concept that appeared in many contexts. Student teachers paid attention to and reflected (except the last attribute) on this as follows:

- Student teachers carried out their designing processes in small groups where they combined different phases of crafts (textiles, design and technology).
- Student groups were a combination of students with varied background specializations (e.g., visual arts, physics and drama), which enable learning from each other's special fields.
- Different disciplines were combined (e.g., crafts, physics, drama and multimedia).
- Craft tasks were connected to societal issues and activities so that student teachers had real-world connections.
- Different arts and skills subjects (e.g., crafts, music, visual arts and physical education) were integrated by a common main theme and common starting and closing activities.
- Teachers/authors (e.g., crafts, physics and drama) made joint interdisciplinary research.

Design education and invention pedagogy: learning by making

Design education refers to a field of doing, making and creating innovative and enjoyable products and services that fulfil human needs and satisfaction (Norman 2013). Today's designing recalls for collaborative inventions, which means that an innovative learning environment should be built so that there is a space for students' questioning, doubting and sharing of knowledge and encouraging them to look for solutions and solve problems. This

thinking comes close to what Hill (1998) has defined as problem solving for real-life contexts in technology, where design processes are creative, dynamic and iterative and where conceptual and procedural phases alternate. Integrating design education, crafts and making activities into the curriculum offers a favourable environment for answering challenges of the twenty-first century and multiliteracy.

Maker and making culture, which has risen mainly in informal learning environments, is currently also gaining ground in schools. Maker culture engages people in DIY and DIWO techniques and processes to develop unique products and has the potential to inspire students into makers instead of just learners and users of current inventions. Maker culture has created environments like Maker clubs, Makerspaces and Maker movement for people to gather, share resources and knowledge, work on projects, learn about technology, solve problems and build (e.g., ELI 2013; Rosenfeld-Harverson and Sheridan 2014; McGlashan 2017). Making in school refers to a meaningful making and innovation education, especially in the STEAM disciplines (e.g., Blikstein 2013a, b; Dillon 2008; Siegel 2008; Sawyer 2014; Kangas 2014; Anttila 2006; Hast 2011; Viilo et al. 2011; Karppinen et al. 2013; Braund 2015; Kallunki et al. 2017; Andersson Schaeffer and Palmgren 2017; McGlashan 2017). For example, an expanding FabLearn labs (established at the University of Stanford, CA, USA) and Co4-Lab and research network (University of Helsinki, Finland) support development of socio-digital invention pedagogy in schools by inquiry-driven action and school-university cooperation.

Alongside digitalization and technological development, crafts and making has gained new interesting dimensions, equipment and methods, such as 3D printers, laser cutters, robotics, coding, e-textiles, smart textiles and wearable technology (see e.g., Pratt IMARI Lab/Pratt Institute 2017; Technology Lab/University of Borås 2017). These new tendencies have opened novel possibilities for making and innovating in schools, also keeping in sight both sensible costs and resources (Karppinen 2017; Andersson Schaeffer and Palmgren 2017; McGlashan 2017). For example, a knitted cap with Bluetooth earphones combines traditional craft with new technology and is called wearable technology (see e.g., Technical Research Centre of Finland 2001; Smart Textiles Design Lab; Pratt Imari Lab). A unique artefact could also be created by combining sewing and embroidery techniques with coding by using conductive metallic thread or pieces of fabric, NeoPixel Ring and a microcontroller (e.g., Flora or Gemma) for programming the LED lights (e.g., using Arduino) to change colour in certain situations, environmental conditions or acts (e.g., sound, music, gesture or knocking). A simple way to light a single LED is to use a battery, magnet and electric wire, and all this could be integrated into an artefact. New technologies also enable participants to fabricate virtually any artefacts, and even young children could construct complex controllable artefacts with hybrid material and virtual features (Seitamaa-Hakkarainen and Hakkarainen 2017).

In this study, design education was applied in a crafts course with the theme ‘smart textiles’. According to our approach, *interdisciplinary design and invention pedagogy*, student teachers explored the field of smart textiles through lectures, brainstorming, data management and prototyping exercises. Prototyping has proved to be a good exercise for context training (Andersson Schaeffer and Palmgren 2017). Student teachers learned that smart textiles are fabrics that are developed by using new technologies to provide added value to the wearer. Clothes are usually meant to cover, protect and make a ‘home’ for a human body, but clothes can also warn, remember, communicate, transform, conduct energy or prevent from some outside stimulus. In addition to learning about possibilities of smart textiles, the student teachers in this study were assigned a task to design their own smart textiles.

Interdisciplinary and collaborative designing as a pedagogic method

In this study, a pedagogic approach, *interdisciplinary design and invention pedagogy*, applied from the LCD model (Seitamaa-Hakkarainen et al. 2010), was used as a pedagogic frame in guiding crafts-designing processes of student teachers (Fig. 1). The LCD model is designed for educational settings to guide and facilitate students' designing processes in technology-enhanced learning. The LCD model represents designing as a spiral and iterative process and illustrates the relations between the elements of collaborative design processes. The LCD model highlights that all participants are working to produce a shared design object by socially shared expertise in all levels of the design process (Seitamaa-Hakkarainen et al. 2010), which also occurred in our course. All participants in the small groups jointly implemented all phases of their designing and activity processes.

The LCD process in this project with distributed expertise was the following: (1) opening day lectures by experts on societal themes (i.e., creating design context); (2) 'kickoff' for creativity and designing; (3) defining a design task with its limitations and brainstorming on the topic of intelligent textiles; (4) students' discussion and designing multiple ideas of intelligent textiles; (5) evaluating design options and searching for more information on the Internet and other sources; and if needed, connecting to an expert to get more information and possible support; (6) experimenting, discovering and creating their authentic design (prototype); (7) testing the design in the real world (e.g., product testing, interviewing people); (8) improving the design as needed; and (9) launching the design in common art subjects' closing day with digital stories of their design processes.

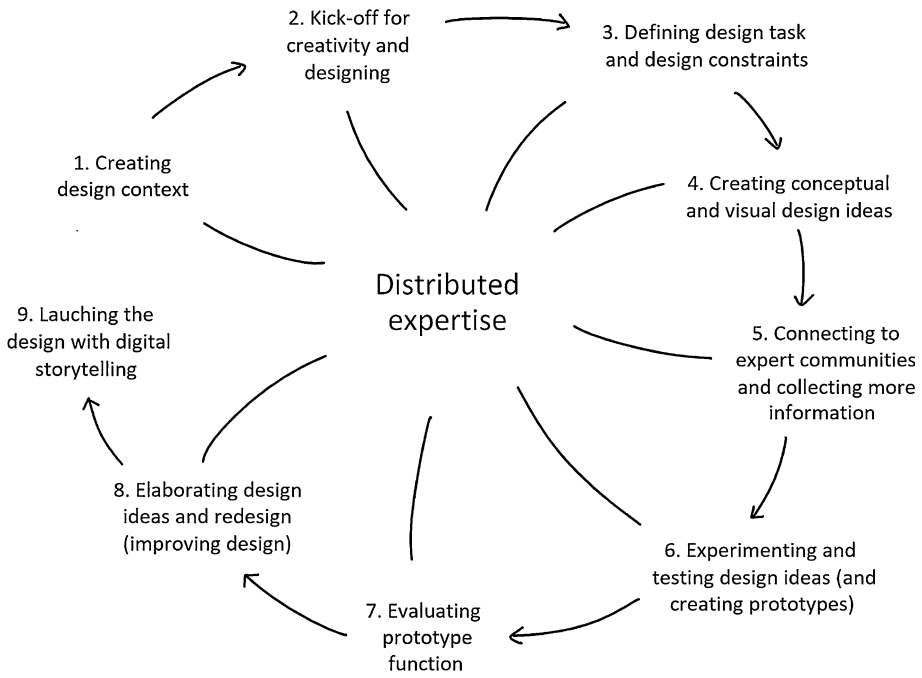

Fig. 1 The pedagogic approach, *interdisciplinary design and innovation pedagogy*, in crafts applied from the LCD model by Seitamaa-Hakkarainen et al. (2010)

As this project was an interdisciplinary project, the LCD model by Seitamaa-Hakkarainen et al. (2010) does not completely cover the activities that student teachers had. Therefore, we add two components to the model. The first one is *kickoff for creativity and designing* by drama performances (see Fig. 2). The activity was meant to orientate student teachers and to open their minds to designing and creativity. The drama teacher performed a theatrical role as a chairman of a big corporation while the students presented different experts within technology and art areas. The corporation wanted to develop varied intelligent clothes, and the chairman persuaded students to create, perform and explain their imaginative creations. That futuristic and absurd event opened student teachers' minds for creativity with a lot of laughs and joy. That was a real kickoff for creativity and designing. In the beginning, this action was noted to be a crucial starting point for student teachers in the design process. It busted out creativity in a delighted way. It also spurred the student groups to be ready for the next steps in the design process. A student teacher aptly wrote in her learning diary: 'Even the craziest ideas could be a basis for new ideas, and there should be time enough for these actions. Also, these kinds of drama situations are brilliant for grouping students and their shared experiences (LD1). Parallel, Langkau et al. (2003) noticed how drama is a practical tool in technology teaching.

The second additional component to the model is *digital stories of the design processes*. Student teachers took photos and videos from the beginning to the end of their designing and product testing processes and created digital stories of the processes. In the closing day of the course, student teachers launched their prototypes and described their design processes to the audience in digital form (e.g., iMovie, Movie maker). In that way, they could wrap up their design and product development processes.

The whole project highlights a DIY and DIWO attitude, participatory practice and constructive creative elements in creating the innovative artefact and its story. It increases engagement on the topic, encourages active participation, blurs the roles of the learner and the instructor and encourages shared learning and creativity (e.g., Lambert 2013; McGee 2015; Niemi et al. 2014; Sadik 2008; Gomez 2015). A salient feature of the applied educational approach is its student-centeredness. In this project, student teachers were

Fig. 2 Student teachers' drama performances

provided technical tools, but the rest was in their own hands—from creating a story about their explorations in the world of smart textiles to their own design.

Research method, data and analysis

This study includes multilevel active participation and planning, following the views of collaborative developmental work research (Engeström 2001, 2013; Galison 1997; Gorman 2005). Collaborative developmental work research refers to cross-border interaction and trading zones (Galison 1997), which involve a common space, shared objectives, joint language and a mutual exchange beneficial to all participants (Engeström 2013; Galison 1997; Gorman 2005), as well as sharing knowledge with one another. One of the aims of the study is to develop our teaching work as educators.

Research data were gathered as student teachers' learning diaries (LD) (total N = 17), design prototypes (total N = 17) and digital stories. Student teachers (N = 60)—30 student teachers per year-long course—made prototypes working collaboratively in small groups (3–5 students per group). Learning diaries were written collaboratively as well but also included individual reflection sections from all. Three student teachers wrote individual diaries. The data were analysed by qualitative content analysis. The data analysis incorporated the following phases: (1) the learning diaries of the student teachers participating in the course were read several times; (2) different descriptions about learning were selected from the data; (3) similar types of descriptions of learning were classified into the same categories; (4) these classes were named, and their contents were reduced; and (5) classes of similar content were included in the same table, and their common meaning was named. This process followed the general principles of an empirical-based content analysis (Patton 2002; Tuomi and Sarajärvi 2009) and was inductive by nature. This means that the researchers' reasoning process was directly based on the empirical data in the learning diaries and digital stories (Tuomi and Sarajärvi 2009, pp. 95–100).

Implementation of the interdisciplinary crafts task

The craft course under the study was carried out twice, in 2014 and 2015, at the University of Helsinki in pre-service primary teacher education as an advanced crafts course of minor studies. Before the advanced course, student teachers had attended a basic crafts course, including both textiles and technology (totally 5 ECTS by European Credit Transfer and Accumulation System). The main goal of the advanced crafts course (3 ECTS) was to get student teachers familiar with different dimensions of crafts (i.e., textile, design and technology), utilize inquiry-based learning and designing and experience potential of interdisciplinary teaching methods. The course was organised temporally at the same time with three other subjects (music, visual art and physical education) with a common opening lecture. This lecture led student teachers into the main themes, which were common with all arts subjects: 'Children's participation by the arts' (in the year 2014) and 'Mind's wellness' (in the year 2015). The crafts course had the subtheme 'Smart clothes or diverse clothes', which inspired student teachers to explore how clothing could separate children from the others or, vice versa, how to protect not being outstripped from a certain society by clothing. In 2015, the subtheme of crafts was 'Mind's wellness through smart textiles'. The crafts courses on smart textiles motivated student teachers to explore in small groups

by brainstorming knowledge about smart textiles, wearable technology and health and wellness and discussing children's participation. In addition to the opening lecture, the course consisted of 20 h of hands-on group work, and in the end, there was a common final closing day together with other art subjects where student teachers launched their innovations. All this was implemented in one-and-a-half months. All students were from primary teacher education, but their prior choices of minor art subject-based courses varied, as well their individual interests and possible prior educations. Therefore, the groups were very heterogeneous, which actually enhanced a fruitful collaboration and knowledge creation.

As a course outcome, student teachers created prototypes of such smart textiles that could also be applied and implemented in basic education. In addition, student teachers made, as part of the course obligations, a video by iMovie or Movie Maker or selection of images about their exploration process (digital story). Student teachers also wrote learning diaries (individual or group ones), which included: (1) written details of the whole process; (2) their thoughts and comprehensions related to the topic and interdisciplinarity with reflections to the theoretical literature; (3) their thoughts about what they have learned during the course related to pedagogy; and (4) a pedagogic plan to implement a craft task in basic education.

Before starting the main task, the technical tools for digital storytelling were introduced and tested. The second activity was to orientate student teachers to open their minds for designing and creativity (drama kickoff). After the drama kickoff, group brainstorming and teacher's lectures on e-textiles and wearable technology, students started designing their own prototypes. Student teachers worked in small groups (3–5 students in a group) using and exploring materials suitable for creating smart textiles, such as conductive thread or fabric, conductive paint, microcontrollers, batteries, magnets and wires. The course was not meant to teach basic elements like sewing, programming, wiring or electrics because these were previously taught in the basic crafts course of textiles and technology. Finally, it was time to use what was learned, transfer that information into practice and explore further.

Results

In the first crafts course in 2014, some student teachers presented their design ideas only at an ideal level, such as marking the smart parts of their creation by using different types and pieces of fabrics. Some of them made authentic creations. In 2015, student teachers created innovative artefacts, clothes and accessories with authentic outfits. They made, for example, a hat with Bluetooth earphones, a cycling glove with an integrated turning signal light, a child's belt with a signal to move after overlong immobility (see Fig. 3) and a sport shirt with a heart-rate monitor.

How does the interdisciplinary design and invention pedagogy in crafts develop student teachers' pedagogic thinking?

The data of learning diaries were analysed through the following stages: (1) the whole data were read throughout several times through the lenses 'How does the interdisciplinary training course develop student teachers' pedagogical thinking?'; (2) the relevant actions

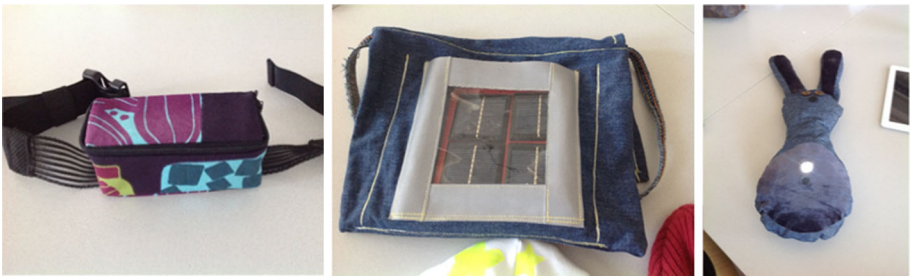

Fig. 3 A child's belt with a signal to move after overlong immobility, a bag with a solar-power charging element for tablets and smartphones, a child's sleeping toy with an LED light

that describe learning were named; from those actions, the first preliminary categories were created (e.g., 'learning together', 'team spirit', 'common goal', ' tolerance in uncertain situations'); (3) preliminary categories were reduced focusing the type of interdisciplinary contexts; and (4) new categories of interdisciplinary contexts were created.

The categories of interdisciplinary contexts are: (1) **holistic crafts,** which are crafts with multi-contextual features (e.g., textiles, technology and design) and multi-materiality (e.g., materials, techniques and equipment); 2) **integrative teaching cross-over disciplines,** which explore creative links between contents of crafts and other disciplines, as well as collaboration between teachers from different disciplines; (3) **digital environment,** which compiles use of ICT and digital devices and applications in connection to designing; (4) **cultural and societal context,** which makes links between crafts and their surroundings and society. Tables 1 and 2 describe with examples what main issues student teachers raised in relation to their learning in pedagogy in different interdisciplinary contexts.

In this study, holistic crafts refers to, first, combined crafts where textiles, technology and designing are all apparent. This kind of approach may raise male student teachers' enthusiasm and interest towards common crafts (LD13). Second, it refers to a process where a craft is seen as a whole process, including designing, creating, planning, implementing and evaluating, as opposed to a partial craft. In the whole craft process, the maker(s) is responsible for ideating, designing the product, planning the implementation and order of its parts, preparing tools and materials, completing the product and assessing the outcome artefact (cf. Whittaker 2014, p. 5; Pöllänen 2009; Rönkä and Aerila 2014). Third, holistic crafts refers to a process where crafts are connected to real-world surroundings, which is linked to integrative teaching of cross-over disciplines and school borders. During the project of smart textiles, the majority of student teachers said they had a good picture about the design process and interdisciplinary teaching. However, they consider that kind of broad project to require good preliminary preparations and detailed working instructions (see Table 1).

The majority (90%) of student teachers listed positive learning outcomes regarding their experiences on this integrative teaching of cross-over disciplines. Outcomes noted were that it opens minds for creativity and new associations, it creates a holistic view of learned issues and it helps to form holistic entities over disciplines (see Table 1). One student raised the point that this kind of activity promotes exploration and learning new concepts through active methods such as mind mapping and drama methods. Another student teacher noticed how she gained further knowledge in technology and better understanding of electricity.

Table 1 Student teachers' learning in pedagogical thinking in relation to holistic crafts and integrative teaching cross-over disciplines

Examples	Learning outcome	Contexts
'To my great surprise I found my own enthusiasm towards the course, not only because there was a lot of space for creativity, but particularly, as a man, to have a possibility to connect technology and techniques to textile crafts!' (LD 13) 'All elements of the whole craft process were fulfilled in a smart textile project, including designing (ideation), planning, experimenting, making, applying, documenting and evaluating. …Especially designing and documenting were emphasized in our project. The long process has to be based on careful planning and experimenting. By making few mistakes and undesired solutions, we achieved a pleasant end product' (LD 10) 'We certainly got new ideas for collaboration, the holistic craft process and bringing together technology and textile crafts… As future primary school teachers we will consider how detailed working instructions help project-based work demands' (LD 16)	Learning about connections within different contents, techniques and materials of crafts Learning how important careful planning, experimenting and documenting of processes are in crafts education Understanding that teaching holistic crafts requires precise instructions	Holistic crafts
'Although, in my opinion, the course was packed with too much of everything, the mess of drama, media education and physics opened a door for fantasy and creativity.' (LD 3) '…In my future teaching I will certainly integrate crafts to other disciplines that emphasise multi-facetedness, importance and societal closeness of crafts' (LD 16/B) 'I gained more knowledge in technology, learned how to create a solar charger and had better understanding of electricity. I think that I am now also better at teaching physics because the theme of smart textiles and our work was integrated well into the physics content. In this kind of project, it would be interesting to highlight to students how different subjects are linked to each other and constitute larger wholes in 'real' life. … My fear about my inability to learn feasible teaching methods in crafts proved to be wrong. I am sure I will consider my future craft lessons in a new light' (LD 16/A)	Learning how to open creativity Learning to see over disciplines Learning new insights for interdisciplinary teaching, learning how to find links to cross-over disciplines and understanding how disciplines form holistic entities in the real world	Integrative teaching cross-over disciplines

LD learning diary

Table 2 Student teachers' learning in pedagogical thinking in relation to the digital environment and cultural and societal context

Examples	Learning outcome	Context
'The course and the task of smart textiles combine in a creative way of basic crafts and ICT. A future teacher needs good skills in ICT, and training has to keep on the development track as well' (LD 7) '–Producing different digital materials with students is concretely "learning by doing" and appears to be meaningful for students' (LD 1) 'Recording videos was very nice…I believe that if adults have so much fun when recording, children would also certainly work on this kind of project with great pleasure. I would absolutely like to use recordings in many other projects' (LD 2)	Understanding the usefulness of ICT skills in teaching Understanding that digital tools are part of an active and meaningful learning process Learning that the use of ICT could be fun for both teachers and students	Digital environment
'Current life clearly requires that crafts are connected to surroundings, culture and society. When I grasped this idea, a totally new view and direction opened to me towards teaching crafts' (LD 1/A) 'When the course was going on, we slowly understood the connection….[with everyday life]. We realized that, for instance, just through crafts we can get these kinds of "big issues" to become a part of everyday life' (LD 15) 'In the beginning it was challenging…to link the societal aspect into the project. However, I think that I have learned a lot from the interview with a policeman…Our aim was to get more societal background and grounds for how schools can increase information about children's traffic security and how this topic could be integrated among others into crafts' (LD 11)	Learning that crafts are closely connected to surroundings, culture and society Learning to see crafts as a part of the broader picture of everyday life Learning how to integrate societal contents with crafts	Cultural and societal context

LD learning diary

Most of the student teachers (93%) considered ICT skills as highly required in teaching, and teachers have to be familiar with ICT and its possibilities (see Table 2). They believed the teacher must be knowledgeable in advanced practices of devices, programmes and applications. Many student teachers said they had plenty of fun using ICT and will definitely use it with their students at school. One student teacher wrote that producing different digital materials with students is definitely 'learning by doing', and that this kind of collaborative process and learning is particularly meaningful for students.

Many student teachers (20%) wrote how in crafts it is possible to teach some broad-based competencies, such as wellbeing, safety or caring for each other introduced in opening day lectures. The majority of student teachers (85%) understood that crafts are tightly connected to surroundings, culture and society, and these issues they want to teach and clarify at school (see Table 2). A student wrote that 'just through crafts, we can understand how "big issues" become a part of everyday life'. Viewing societal themes

from a standpoint of phenomenon-based interdisciplinary-approach crafts gave a good ground for discussing these issues.

How can other disciplines enhance the crafts-designing process?

In the beginning, most of the student teachers (90%) felt that the course was very confusing because it included so many integrative elements and tasks, but in the end, the majority (93%) had positive experiences and learning outcomes from the project. One student teacher compresses: 'in the end, all elements formed a very clear entity' (LD 3). Most of them particularly enjoyed drama exercises and said that they will certainly integrate drama with crafts in their future teaching and with other disciplines as well. Designing drama could offer a beneficial platform for revealing creativity as we call it a 'kickoff' for creativity and designing. 'It is important', as a student teacher wrote, 'to give students space for creativity in school because designing is a significant part of any process. In drama exercises, even exponential thoughts and ideas may appear that could be possible to implement. In addition, teachers may get new ideas and enhance knowledge' (LD 6). However, not all student teachers (7%) were enthusiastic about the project. Two of them were hesitant to implement a smart textiles course in primary school because they found the issue very challenging. However, another two of them found that a good group spirit helped them to carry on the project and implement the design. These kinds of hesitations might be due to lack of feeling competent, and they might take the situations emotionally (compare cognitive/emotional dissonance theory; Vygotsky 1987).

However, after all, the majority (93%) were more or less in favour of the topic 'smart textiles' and its feasibility for implementation in primary school. As a student teacher wrote: 'I am now braver in encouraging students to create experimentation and inquiry learning' (LD 10). What was most visible in their comments was that there is a clear change in attitude towards interdisciplinary teaching and crafts designing.

In all, majority of the student teachers (93%) found the topic interesting, they gained new perceptions and feasible ideas to use in basic school crafts and they learned how the real process of product development is implemented. They also found that this kind of project requires precise instructions as well as good preliminary preparations.

Conclusion

This paper discusses how the *interdisciplinary design and invention pedagogy* in crafts education develops student teachers' pedagogic thinking and their learning outcomes. The main conclusions are that student teachers found a new way to think and organize interdisciplinary teaching; positively changed their attitudes towards interdisciplinary teaching; and discovered new ideas and found the courage to implement teaching of cross-over disciplines, not only over the subjects employed here but in any combination of subjects. Furthermore, there were already visible signals of enthusiasm to employ these skills in different contexts (transferable skills).

This paper presents an example of interdisciplinary teaching project where crafts, physics, drama and ICT are combined with an example of an inner integrative crafts project combining different content areas of crafts: textiles, technology and design education. This teaching intervention was just an example of a cross-disciplinary process, and

the combination of subjects could be anything. The study is part of a broader research project on interdisciplinary teaching in the university context (Karppinen et al. 2012, 2013), in primary school contexts (Kallunki et al. 2017) and in the context of in-service teacher training (ongoing research). As a practical outcome, this study gives an example of a teaching module that could be used in primary school where the starting point is the core elements of crafts.

Interdisciplinarity is a natural part of the school subjects chosen in this teaching intervention. Crafts and crafts education touch on many disciplines and scientific areas, such as psychology, economics, natural sciences, technology, culture and the social environment (Anttila 2006). Thereby, there are natural interconnections between the core elements of crafts, technology and the natural sciences (e.g., Hast 2011; Viilo et al. 2011) as we have tried to highlight in this course project and the study. These elements and their interconnections just have to be discovered by students and student teachers. As the new national curriculum of basic education (Finnish National Board of Education 2014) guides crafts education for multi-materialism, crafts expression, designing, holistic crafts, employment of technology and interdisciplinary approach (pp. 146–148, 270–273, 430–433), we as teacher educators aim to display some examples of how to implement these in practice.

Drama, the other interventional supporter of the crafts course, is an interdisciplinary principle, which can be used to challenge different disciplines in teaching and interdisciplinary projects. In every case, drama exercises and methods develop skills, such as interactional, reactional and concentrational skills, as well as open channels for multisensual and phenomenal experiences, which can lead to a deeper understanding of learned issues (Heikkinen 2005). Drama methods make it possible to 'use' the whole body (the potentiality of senses and feelings) during the learning process (c.f. Siegel 2008).

In physics, interdisciplinarity manifests itself in the broad-based nature of the science. Classical physics, through its energy concept, covers a wide variety of natural phenomena such as mechanics, electromagnetism, acoustics, optics and thermodynamics, which makes it possible to find convergencies to almost all other school subjects. On a more general level, physics has its own role among all school subjects in the field of human culture. This means that it can be seen as part of the fruitful interaction that builds up each student's world view (Kurki-Suonio and Kurki-Suonio 1994, pp. 74–76).

The course as such was very intensive, including varied contents and approaches. Therefore, students felt very confused in the beginning. However, as a student teacher writes: 'Despite arousing suspicions in the beginning, I had plenty of good experiences and thoughts to use this kind of interdisciplinary approach later on in my future teaching in school' (LD 5). Smart textiles (e.g., e-textiles and smart clothes) fit excellently to Finnish crafts education as it offers a new and innovative environment to benefit varied content areas of crafts as well as new ICT. These kinds of activities, where creativity, sharing, invention, imagination (Dewey 1933; Siegel 2008; Blikstein 2013a, b; Seitamaa-Hakkarainen and Hakkarainen 2017) and ICT are in the midpoint, are important in current and future education (e.g., Wilenius 2015, p. 169; Lipponen and Rönnholm 2016, p. 30; Tulevaisuusvaliokunta 2013) and may, in the best cases, increase students' motivation for school work and school satisfaction. Making culture could be also a response to Jonathan Osborne's and Justin Dillon's (2008) statement of missing interest from students towards science education.

As pre-service student teachers are in the process of learning to teach, feelings of uncomfortableness and incompetence may play a big role. Therefore, a developmental viewpoint for our further research could be to pay more attention to student teachers'

emotions by using Lev Vygotsky's (1987) dissonance theory. Vygotsky's theory might especially give support for analyzing situations where student teachers feel themselves confused because of the cognitive/emotional dissonance.

The interdisciplinary education and innovative making in schools require a new way of thinking and discussion about education—how to plan, design and organize formal education. However, student-centered self-piloting and lateral learning, rather than a top-down model, is a much more authentic representation of how learning happens in life. The teacher's role as facilitator, supervisor, animator or adviser is recommended to support student-generated activities.

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