FORMakademisk

Vol. 9, Nr 1 (2016)

Embodied Making and Design Learning

Special Issue from the Learn X Design-conference DRS/CUMULUS, Chicago 2015

FORMakademisk

Table of contents:

Editorial

Embodied Making and Design Learning - Special Issue from the Learn X Design-conference DRS/CUMULUS, Chicago 2015

Marte Sørebø Gulliksen, Catharine Dishke Hondzel, Pirita Seitamaa-Hakkarainen, Tellervo Härkki

Articles

Embodied Making, Creative Cognition and Memory

Marte Sørebø Gulliksen

Personal exploration: Serendipity and intentionality as altering positions in a creative process

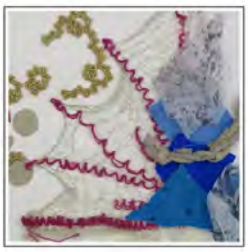
Maarit Mäkelä

How can neuroscience help understand design and craft activity? The promise of cognitive neuroscience in design studies

Pirita Seitamaa-Hakkarainen, Minna Huotilainen, Maarit Mäkelä, Camilla Groth, Kai Hakkarainen

Design- and Craft thinking analysed as Embodied Cognition

Camilla Groth



Material knowledge in collaborative designing and making - A case of wearable sea creatures

Tellervo Härkki, Pirita Seitamaa-Hakkarainen, Kai Hakkarainen

Marte S. Gulliksen, Catharine Dishke-Hondzel, Tellervo Härkki and Pirita Seitamaa-Hakkarainen

Embodied Making and Design Learning

Special Issue from the Learn X Design-conference DRS/CUMULUS, Chicago 2015

Abstract
This issue of FORMakademisk features selected articles developed from papers presented at the symposium Embodied Making and Design Learning at the DRS/CUMULUS-conference LearnXDesign in Chicago, Illinois, June 28–30, 2015. This special issue was developed as an initiative by the symposium conveners. The symposium was developed by researchers from research groups in Norway, Finland and Canada to explore various aspects of embodied making in relation to design learning. The symposium was a full-day event with four sessions, seven paper presentations, a roundtable discussion, a plenary discussion and a workshop. The symposium received positive feedback, attracting many participants and stimulating engaged discussions throughout the conference. This indicates a growing awareness of the topic of embodied making and design learning. This special issue features five articles that together highlight a variety of approaches and examples of current research endeavours in relation to the theme.

Keywords: embodied making, design learning, DRS/CUMULUS

This issue of *FORMakademisk* features selected articles developed from papers presented at the symposium Embodied Making and Design Learning at the DRS/CUMULUS-conference LearnXDesign in Chicago, Illinois, June 28–30, 2015. This special issue was developed as an initiative by the symposium conveners. The aim of the symposium was to discuss the role of embodied making in design learning. The term 'embodied' indicates a perspective on experiences as a unity of cognitive and bodily processes (Rosch, Thompson, & Varela, 1991). Theories on the embodied mind have gained considerable momentum throughout the last decades, supported by knowledge from neuroscience on how the brain processes information (Gulliksen, Groth, Mäkelä, & Seitamaa-Hakkarainen, 2016). Embodied making is, in this context, a term used to describe the processes of making in materials – experiences when making artefacts or engaging in other creative activities with materials (Dunin-Woyseth & Nielsen, 2004; Fauske, 2013; Nilsson, 2013).

One main aim within studies of embodied making is to explore the basic conditions and consequences of being a body in the world, experiencing and learning through working in and with materials. The theme is approached using an interdisciplinary lens encompassing a variety of methods such as video recordings, neuro-scientific methods and stimulated recall.

The symposium was developed by researchers from research groups in Norway, Finland and Canada to explore various aspects of embodied making in relation to design learning. The facilitators of the symposium come from a variety of backgrounds across the humanities and social sciences, in particular, art and design, design education and craft science, educational neuroscience and phenomenology. The participating research groups include: The Embodied Making and Learning research group from Telemark University College (now the University of Southeast Norway); the Handling Mind research consortium from Aalto University and the University of Helsinki, Finland, and the Human Ingenuity Research Group from Western University, Ontario, Canada.

The participants in the symposium were (in order of the programme):

- Marte S. Gulliksen, Professor, Telemark University College, Norway (now University College of Southeast Norway)
- Pirita Seitamaa-Hakkarainen, Professor, University of Helsinki, Finland
- Maarit Mäkelä, Associate Professor, Aalto University, Finland
- Catharine Dishke-Hondzel, PhD, Western University, Canada

- Joel Lopata, PhD, Western University, Canada
- Camilla Groth, Doctoral Candidate, Aalto University, Finland
- Tellervo Härkki, Doctoral Candidate, University of Helsinki, Finland
- Brynjar Olafsson, Doctoral Candidate, Telemark University College, Norway (now University College of Southeast Norway)

The symposium aimed to bring these researchers and research leaders together to discuss both the selected topics of embodied cognition in making and design learning and future possibilities for uniting the human capital of each group within a global, co-owned research project.

The symposium was a full-day event with four sessions, three of which were open to the public. A total of seven papers were presented in addition to one round-table discussion and one plenary discussion, which were open to all participants at the LearnXDesign conference.

	Topic	Responsible	Time frame
	8-9 am: Registration		
	9:00-9:30 Welcome		
	09:30-09:35 Welcome to the symposium	Gulliksen	5m
Session 1: Making, creativity and cognition	09:35-09-50 Creative cognition and embodied making	Gulliksen	15m
	09:50-10:05 Creating the space/conditions for creativity	Lopata	15m
	10:05-10:20 Embodied making and creative practice	Mäkelä	15m
	10:20-10:30 Questions	Gulliksen	10m
	10:30-10:45 Break		
Session 2: Learning and embodied making	10:45-11:00 What neuroscience can tell us about skill learning in craft: The promise of cognitive neuroscience in making	Seitamaa-Hakkarainen	15m
	11:00-11:15 Engaging users in the design of post-secondary teaching and learning spaces	Dishke-Hondzel	15m
	11:15-11:45 Round-table discussion -	Gulliksen & facilitators	30m
	11:45-13:30 Lunch		
	13:30-14:30 Keynote ENMESH + Panel debate		
	14:30-14:50 break		
Session 3: The body seen in design practice	14:50-15:10 Design and craft thinking analyzed as a form of embodied cognition	Groth	20m
	15:10-15:30 Approaching embodied experience of materials and materiality	Härkki	20m
	15:30-15:45 Plenary discussion	Gulliksen	15m
	15:45-16:15 Break		
Session 4:	**16:15-17:15 Workshop - closed session**	Gulliksen & facilitators	65m
	End of day 1		
	18:30 reception		

Figure 1. Graphic presentation of symposium, Sunday June 28, 2015

The symposium received a positive response, with several conference delegates choosing to participate and engage in discussion, indicating a growing awareness of the topic. The discussions continued at the DRS2016 conference in Brighton, June 2016, where representatives from the same group organised an additional theme session: Embodied Making and Learning (http://drs2016.squarespace.com/additional-themes/).

This special issue features five articles that together show a variety of approaches and examples of current research endeavours related to the theme. They are based on papers presented at the symposium. Two independent pairs of section editors had the editorial responsibility for this special issue. One pair, Gulliksen and Dishke-Hondzel, edited the articles by Groth, Härkki et al., Seitamaa-

Hakkarainen et al. and Mäkelä. The other pair, Seitamaa-Hakkarainen and Härkki, edited the article by Gulliksen. At no point during the editorial process were the authors of the articles involved in the editorial process of their own article. This system was approved and monitored by the editor-in-chief of *FORMakademisk*, Janne Reitan.

Articles in this Issue

In the first article, Professor ***Marte S. Gulliksen*** from the University College of Southeast Norway focuses on creative cognition and the neurobiological basis of making with an emphasis on the role of the hippocampus in storing and recollecting declarative episodic memories. Revisiting the previous experience of her own woodcarver, and engaging again in woodcarving, Gulliksen explores the complexities of woodcarving from a neurobiological point of view, giving special attention to perception, thalamic attention, memory and neuroplasticity. Through this exploration, three tentative ideas for developing future interdisciplinary studies emerge. The author argues that such studies could be useful in understanding the role and purpose of woodcarving, as well as other making activities, in today's society.

Associate Professor ***Maarit Mäkelä*** from Aalto University examines the nature of embodied learning and the environment in Tasmania and New Zealand in her article Personal Exploration: Serendipity and Intentionality as Altering Positions in a Creative Process. Mäkelä explores complex ideas about the nature of embodied making, learning and discovery while reflecting upon the process and outcomes of her daily hikes through forests, beaches and hills as she travels to and from her studio. Over the course of several months, Mäkelä gathers ideas and inspiration from her natural environment and documents how they were then incorporated into her creative practice. Her research and process journals are used as primary sources of data to inform how the acts of walking and collecting served as catalysts for creative idea generation in the practice of her art. The paper demonstrates a means of active engagement in the process of creating while teasing apart how materiality, reflective practice and mental space inform the process of circumambulatory knowing.

Authors ***Pirita Seitamaa-Hakkarainen*** (Professor, University of Helsinki), ***Minna Huotilainen*** (Research Professor, Finnish Institute of Occupational Health – Brain and Work Research Centre), ***Maarit Mäkelä*** (Associate Professor, Aalto University, Finland), ***Camilla Groth*** (Doctoral Candidate, Aalto University*)* and ***Kai Hakkarainen*** (Professor, University of Helsinki) examine the promise of cognitive neuroscience in design studies as part of their project Handling Mind: Embodiment, Creativity and Design. The authors offer a comprehensive literature review, which provides a succinct description of the previous research on design cognition and embodied thinking and learning. Following this, the article explores and describes the relevant cognitive neuroscience methods that can be applied to design research in order to study the effects of designing and skill learning. Drawing on their own programme of research on experimental brain research methodologies, the authors provide a rich description of the benefits and drawbacks of specific neuroscientific methods, including fMRI, EEG, MEG, MRI, PET and NIRS techniques, recognising that to effectively study embodied learning, craft and design, the body must often be able to move. This article provides a concise overview and analysis of the methods and techniques that can be appropriately used to examine embodied learning in design thinking within the area of cognitive and neuroscientific experimental studies. Specific examples of skill learning with regard to craft and design enhance and expand our understanding of learning and skill acquisition.

Camilla Groth is a doctoral candidate at Aalto University School of Art, Design and Architecture. Her article – Design and Craft Thinking Analyzed as Embodied Cognition – presents three case studies exploring embodied cognition in design and craft practices. The aim of the case studies is to understand how sense-making takes place through the physical manipulation of materials or, put differently, how the process of physically handling materials creates specific cognitive sensations. In the first case, Groth's examination involves ceramic workshops with deafblind makers. As an active participant and guide through the making process, the author documents and reflects on the manner in which deafblind makers rely on haptic sense-making in order to create and form ceramics. Drawing on lessons learned from this workshop, the second case study explores Groth's personal experience, blindfolded in her studio, throwing clay cylinders on her potter's wheel. This work was video recorded, and subsequent video analysis revealed 'critical incidents', the reciprocal nature of materials and physical experience as well as the emotional impact and discovery in blindfolded ceramic work. The third case study explores how students make choices about material selection and the words they use to describe the associated feeling and sensations. Together, these three cases provide an opportunity to understand how the process of making is informed by complex and diverse physical sensations and emotions that go beyond language. Groth concludes her article by discussing the nature of tactile experience and how the body informs works of the imagination and the ways in which mental images are formed.

In the final article, ***Tellervo Härkki*** (Doctoral Candidate, University of Helsinki), ***Pirita Seitamaa-Hakkarainen*** (Professor, University of Helsinki) and ***Kai Hakkarainen*** (Professor, University of Helsinki) investigate students' relationship with materials and materiality, focusing on the embodied experience of various materials over the course of a collaborative design assignment. The authors are interested in a better understanding of making and materiality from two standpoints: the nature of the knowledge shared during the process of designing and the knowledge shared between students during the process of making. Students registered on the course participated in the study as consultants to a local aquarium. The aquarium had requested custom-made accessories to be used by groups of visiting children. Using excerpts from student journals and interviews, as well as qualitative video analysis, the authors describe the various ways in which students made decisions about the design and making process of creating the accessories. The authors conclude that students' experiences of design and creation are communicated in many ways, including in the forms of speech and gestures. This article expands our understanding of communication in making and design and reinforces the complex ways in which making and materiality are embodied.

Together, these five distinct articles demonstrate a variety of ways in which embodiment occurs in making and design education and highlight diverse perspectives in the field of design education research.

Notodden, London (Ontario), Helsinki, June 2016

Marte S. Gulliksen	*Catharine Dishke- Hondzel*	*Pirita Seitamaa-Hakkarainen*	*Tellervo Härkki*
Section Editor	Special Issue Editor	Special Issue Editor	Special Issue Editor

Marte S. Gulliksen
Professor, PhD
University College of Southeast Norway, Faculty of Art, Folk Culture and Teacher Education
Email address: marte.gulliksen@hit.no

Catharine Dishke Hondzel
Coordinator of Research and Learning Support, PhD
Huron University College
Email address: cdishke@uwo.ca

Pirita Seitamaa-Hakkarainen
Professor of Craft Studies, PhD
Helsinki University
Email address: pirita.seitamaa-hakkarainen@helsinki.fi

Tellervo Härkki
Doctoral Candidate, MSc, MA in Ed.
University of Helsinki, Faculty of Behavioral Sciences
Email address: tellervo.harkki@helsinki.fi

References

Dunin-Woyseth, H., & Nielsen, L. M. (2004). *Discussing transdisciplinarity: Making professions and the new mode of knowledge production: the Nordic reader 2004*. Oslo: Oslo School of Architecture and Design.

Fauske, L. B. (2013). Making scholarship: Describing the field of inquiry and the research approach. *Proceedings of the 2nd International Conference for Design Education Researchers* (pp. 508 –517), 14–17 May 2013, Oslo, Norway.

Gulliksen, M. S., Groth, C., Mäkelä, M., & Seitamaa-Hakkarainen, P. (2016, 27–20 June 2016). *Introduction to additional theme session 4 – Embodied making and learning.* Paper presented at the DRS2016, Brighton.

Nilsson, F. (2013). Knowledge in the making. On production and communication of knowledge in the material practices of architecture. *FORMakademisk, 6*(2), 1–13. Retrieved May 15, 2016 from https://journals.hioa.no/index.php/formakademisk/article/download/569/659

Rosch, E., Thompson, E., & Varela, F. J. (1991). *The embodied mind: Cognitive science and human experience*. Boston, MA: MIT Press.

http://dx.doi.org/10.7577/formakademisk.1487

Marte S. Gulliksen

Embodied Making, Creative Cognition and Memory

Drawing on neurobiological knowledge of creative cognition and the role of the hippocampus in memory storage and recollection to explore the experience of carving green wood

Abstract

This article revisits previous research on the maker's experience when working with materials, and discusses this in light of new research on creative cognition and the neurobiological basis of making. It is one in a series of four articles, which draw on neurobiological knowledge to expand our understanding of the woodcarver's experience. The aim of this article is to present and discuss one element of the creative cognition of the woodcarver: memory. It reviews the basics of the nervous system and its function, cognition, and attention. I argue that one of the reasons why the woodcarver cherishes the experience of carving is that he or she can recall and relive many details in the memory of it. I will specifically discuss the role of the hippocampus in storing and recollecting declarative episodic memories. The article concludes with a short discussion of why this knowledge is useful in understanding the woodcarver's experience and, in turn, if – and, if so, why – woodcarving could be an important activity in which to engage in the twenty-first century.

Keywords: embodied making, neurobiology, memory, cognition, hippocampus

Introduction

Embodied making with green wood – revisiting a previous study

Figure 1. Working with green wood.

The experience of working with green wood (figure 1) is often described as a *making* process (Michl & Dunin-Woyseth, 2001), involving intense internal focus, immense joy, and an urge to overcome resistance (see, for example, Crawford, 2009; Dahl & Dahl, 2015; Fredriksen, 2013; M. S. Gulliksen, 2015c; Ingold, 2013; Osborne, 2014). Such experiences are *embodied*

(Rosch, Thompson, & Varela, 1991), meaning that the abstract cognitive process and the physiological, bodily process are intertwined and inseparable. They have been referred to as experiences of flow (Csikszentmihalyi, 1996) or as the experience of being creative. The term "creative cognition" is used to describe creativity as a distinct creative mental state. Developed from the functional neuroanatomy framework of creativity described by Dietrich (2004), the term has been defined by Lopata (2014, p. 8) as: "a distinct mental state that includes (a) engagement in an activity, (b) spontaneous processing of thoughts, and (c) the expression of these thoughts through a medium (e.g., voice, a writing tool, a musical instrument)".

This article addresses the themes of embodied making, creative cognition, and memory via the carver's experience of making objects in wood. Early in my research career, I studied my own woodcarving experience (M. Gulliksen, 1997, 2001), through a rigorous analysis supplemented by poetic descriptions:

> Slowly, warmth spreads from within my body – hands soar, clutching the iron as shapes evolve. I fight the wood in the first phases: The gouge is pressed down and wriggled forward, resulting in notches left to be smoothed by a knife. This part of the work feels like an exhausting negotiation between two wills. The wood and I have to compromise. I introduce my original idea about figure and shape like persuasion with gouge and club.
>
> I know this piece of birch wood already. There are some wounds along a growth ring, as if it has torn. Ax traces from the felling. I can see traces left by the power of my arm wielding the ax when felling the tree. In my memory, I have stored images of the instant it fell down. And of the instant before, when it still stood tall, up in the mountain forest. The little bowl shape is carved out of a tree that, had I not felled it, would still have been towering over the forest and shaking its leaves for several decades to come. So I chop it down and clamp it to the work bench. I attack it with tools; making holes where before there were unbroken lines, growth circles, life. I make dents where before there were untouched fibers. Peel off the bark and, underneath, the grain is smooth as silk.
>
> Reluctantly, the wood gives in, with chips falling off in their own tempo and their own direction. Before my eyes, shapes are erased and arise from shivering growth rings under the gouge's strive. Hard labor and physical strength wriggle the idea into shape.
>
> The wood needs a long period of intense persuasion to accept my ideas, and my ideas need time to adjust to the wood. But when the shapes are found at last, the knife follows the directions of the fibers. When they meet, the fibers and the knife, they unite like rivers connect, meet gliding down through shallow valleys (M. Gulliksen, 1997, pp. 64-65, 76, my translation).

Describing the experience in such ways worked as an experiential conceptualization in the study, reflecting the experience of making itself and seeking to capture some of its complexity. In the previous study, I drew upon Merleau-Ponty's perception phenomenology (1962) to analyze this activity. The study was situated within a phenomenological research tradition, positioning the body as a vehicle for being in the world (Streeck, Goodwin, & LeBaron, 2011). Studies on embodied making within the design and craft education research tradition have often drawn on such perspectives, in addition to other descriptive and/or philosophical approaches, such as the philosophy of Bergson (Bergson, 1988; Østerberg, 1995), and socially and culturally contingent perspectives, such as Bourdieu's descriptions of habitus (Bourdieu, 1984; Bourdieu & Johnson, 1993).

The previous study described an activity moving through several different conceptual states of mind, from the intense sensory experience to critical reflections. Drawing on Merleau-Ponty's phenomenology, I referred to this as experiences having a preconscious and a conscious mode. In these modes of experience, the *maker*, i.e., the embodied unity of mind and body (Bresler, 2004; Rosch et al., 1991; Varela, Vermersch, & Depraz, 2003), and the *material*, i.e., the unity of form and matter (M. Gulliksen, 1997; Karlsen, 1994), were engaged in a negotiation, during which the maker's initially vague intentions and projections for the process's intended results were met and reshaped by the material's physical and abstract properties. The negotiation led to the overcoming of three types of resistance between old and new ideas and experiences: physical resistance, aesthetic–idea resistance, and cognitive resistance (M. Gulliksen, 1997, 2000, 2001). In that study, I was interested in understanding how sensory motor and cognitive experiences seemed to melt together in this preconscious state of mind. In accordance with the perception phenomenology of Merleau-Ponty, this negotiation process could be understood by grasping what perception is: beyond merely experiencing the material and what we are doing in a situation, our intentions shape the phenomenon itself. The negotiation between maker and material is thus "a perceptual field opening up to the body" (Gulliksen, 2001, pp. 4-5). This description of an embodied cognition aligns with other accounts; see, for example, O'Connor's descriptions of learning to blow glass (2005) or Groth's descriptions of throwing clay (2015; 2013).

Lately, knowledge from the rapidly developing neurosciences has informed creative practices and embodied making from novel perspectives (Seitamaa-Hakkarainen, 2015). Such knowledge opens up the field for other nuanced perspectives explaining the biological functions behind the phenomenological descriptions from the last century. In particular, studies conducted jointly by researchers from the practice fields and the science field have advanced our understanding of the biological basis for the designer's or artist's experiences (Goguen & Myin, 2000; Seitamaa-Hakkarainen, 2015; Seitamaa-Hakkarainen, Huotilainen, Mäkelä, Groth, & Hakkarainen, 2014; Varela et al., 2003; Zaidel, 2005). Similar results emerge from the fields of education or development studies, where such interdisciplinary perspectives have been found to support and expand previous research on complex human behaviors, development, or experiences (Ansari & De Smedt, 2012; De Smedt et al., 2011; Juelskjær, Moser, & Schilhab, 2008; Simons & Klopack, 2015).

The context – developing an interdisciplinary research project

This article is written within the context of an ongoing project that aims to develop a future interdisciplinary study of embodied making activities, bringing together neuroscientific and experiential, observational, analytical, or reflective knowledge and methods. Such an interdisciplinary study combining these different methods could potentially confirm and expand current knowledge on both the phenomenon of embodied making itself and learning in and through such making. The project aims to provide a coherent description of certain relevant neurobiological knowledge, to generate a starting point or a foundation for developing hypotheses for the future interdisciplinary study. In order to achieve this, I have written and discussed papers at international conferences, studied in courses, and organized seminars and workshops on this topic. I also practice woodcarving myself, within the context of this project development (see Figure 2 on the next page).

The project exemplifies making in wood, keeping in mind that the neural and functional distinction between woodcarving and other making activities may be small. Nevertheless, I assert that it could be possible to use neurobiological knowledge to gain a better understanding of why woodcarving, for so many, is intensely experienced and vividly remembered, and to generate new and communicable knowledge on if – and, if so, why – these experiences are important enough to pursue in education or in daily life.

The present article, written within this context, is the second in a series of four, of which three explore different neurobiological themes: the present article, another article that focuses on the role of the cerebellum in woodcarving (M. S. Gulliksen, 2015c), and a third that focuses on the role of the thalamus in directed attention in sensory experiences (M. S. Gulliksen, 2015b). The fourth article presents the project of developing a future interdisciplinary research project on neuroscientific knowledge in embodied making itself (M. S. Gulliksen, 2015b, 2015c, 2016b). There are plans for two more articles: one focusing on methodologies for the future project (M. S. Gulliksen, 2016a), and one in which I intend to discuss experience-dependent neuroplasticity and questions related to learning-induced autonomy of the sensory motor system (Basset, Yang, Wymbs, & Grafton, 2015).

Figure 2. Wooden bowl inspired by the form of a cerebellar Purkinje cell. Aspen wood, 35x7x3cm. Made while writing this article and given to Professor Peggy Mason of the Department of Neurobiology at the University of Chicago.

I am no neurobiologist. Currently, I hold the position of professor in culture education, culture production, and aesthetic practice at the University College of Southeast Norway. From this perspective, I have followed the knowledge generated in the neurosciences for some twenty years, and have participated in seminars and attended relevant courses (e.g., Mason, 2015; Western University, 2014). The immediate danger of discussing neurobiology without full scholarly knowledge of the field is that non-scientists tend to make overly strong claims based on inadequate understandings of the concepts (De Smedt et al., 2011; Goswami, 2006; Western University, 2014). There is also a concern about neuroscience content or terms being used "purely to put a new, modern gloss on some very old ideas from 1970s psychology. This is not to say that it is necessarily bad advice. But these are old ideas, given a slick re-packaging and being sold as brand new" (Wall, 2014, para. 12).

These concerns are the reason for writing a series of articles and discussing them with experts in the field. Aiming to bring together current neurobiological descriptions of what the woodcarver does and experiences in a coherent way, as seen from his or her own perspective, the descriptions can engage critical thoughts and new ideas on where to begin developing hypotheses for a future interdisciplinary study. Together, the articles are intended to form a basis for further exploration of the theme, in association with specialists in the neurosciences, within the framework of our international research group consortium and our university research group, Embodied Making and Learning, at the University College of Southeast Norway (M. S. Gulliksen, 2015a).

Aim of the article

In this article, I revisit the earlier study on woodcarving (Figure 3) described above (M. Gulliksen, 1997, 2000, 2001), as well as engaging again in woodcarving. The primary objective of the article is to present and discuss, from a neurobiological perspective, one specific aspect of the woodcarver's cognition: his or her memory of it. Carving, like every other activity in which a person can engage, is dependent on a combination of immediate memory, working memory, and long-term memory. Looking more closely at what memory is from a neurobiological perspective could therefore be relevant. To do that, I will need to present a definition of cognition and the phenomenon of attention. I do not so much discuss whether this cognition is creative or not, but rather consider a limited range of cognitive activities in the maker's experience and the memories of these experiences, which could, by some definitions, be seen as a form of creative cognition. I will argue that one of the reasons why the woodcarver cherishes the experience of carving is that the memory of it can be recalled and relived in great detail. In particular, having presented a short overview of the basics of the nervous systems and its functions, I will discuss the role of the hippocampus in storing and recollecting declarative episodic memories.

Figure 3. Carving a bowl in birch wood (1997).

As a creative making activity, woodworking has many similarities to making with other materials. I choose green woodworking specifically for a number of reasons, principal among which is my personal background as researcher and maker. Woodworking is a slow process: it is hard labor, engaging many senses and the entire body, and many different countries across the world have developed a strong cultural tradition of working in wood, as wood has traditionally been easily accessible and can be turned into useful and/or beautiful objects by a multitude of techniques. However, in post-industrial countries, the activity of woodworking is fairly rare, and even more rarely researched compared to other making activities such as music, drama, or even art therapy (Hass-Cohen & Carr, 2008; Winner, Goldstein, & Vincent-Lancrin, 2013). There is thus a lacuna in science-based knowledge on woodworking, which makes it relevant to contemplate. In this particular article, however, woodworking is seen as an example of a making process, as the knowledge presented may not necessarily be confined to woodcarving.

The professor in the neurobiology course I attended discussed an early version of this article, which was also presented as a paper at the LearnXDesign2015 conference to researchers within the fields of design and education at the symposium "Embodied making and design learning."

The nervous systems and its functions

Neurons and neural communication

Neurons are the name of the types of cells responsible for registering, translating, and transmitting information in the body. The term neurobiology refers to the study of the basic nervous system in all animals, including humans (Mason, 2011; Purves et al., 2012).

Neurons are organized in two main systems: the central nervous system (CNS), which includes the forebrain, brain stem, and spinal cord, and the peripheral nervous system (PNS), which includes all the other neurons sending or receiving information to and from the CNS

(Mason, 2011, p. 4). The nervous system has four basic functions: voluntary movement (everything we choose to do), perception (everything we consciously appreciate), homeostasis (the continuous process of keeping our body balanced and alive), and abstract functions (everything we think, feel, learn—what makes us a human being) (Mason, 2015).

The neurons communicate with one another and with other types of cells, such as muscle cells. The neurons relay information by means of electricity. At rest, the neuron has a resting membrane potential, a stable difference in electrical voltage between the outside and inside of the cell. One dedicated part of the cell, the dendrites, is responsible for registering information from other cells or from the outside world. This registration leads to a stimulus of or a change in the electrical voltage in the cell: the release of an action potential. This elevated electrical voltage will form a rhythm and intensity that together function as a signal that moves through the neuron toward the cell body, the soma, where it is processed and sent further down the neuron's axon. At the axon terminals, the action potential releases neurotransmitters that make up a chemical message, which transmits the signal to other neurons' dendrites in a synapse or by innervating another type of cell, for example muscle cells (Mason, 2011, p. 55). The signals can be affirmative, negative, fast, and slow. Each neuron is responsible for conveying a particular message.

Neurons register information from the outside world by a process called transduction. During transduction, the dendrites of the neurons register signals from the outside world (light waves, sound waves, mechanical pressure on our bodies, etc.), which, through a range of different means, stimulates the neuron and releases an action potential that sends the electrical signal into the nervous system. Whether originating from a transduction process or from processes within the nervous system, these electrical signals are therefore the means by which we can breathe, see, move, and think—everything we are as living bodies.

For the woodcarver, as for every other animal with a brain, many types and circuits of signals are active at the same time, as an integrated whole. This is why experts in the field emphasize that the "assignment of a function or functions to certain neurons or brain regions should not be viewed as a precise description of nervous system operation, but as a current best guess and as a teaching device" (Mason, 2011, p. 22). The different brain regions work together to process information and respond to it. Studies of functional connectivity (two areas of the brain that fire at the same time) and effective connectivity (firing in one area triggers firing in another area) are made possible by new technological advances (Friston, 2002). Knowledge of the whole brain's functional integration shows promise for future studies that could shed light on making activities—what is shared and what is particular to woodworking, compared to other making activities (Rosa, Daunizeau, & Friston, 2010). However, in order to deal with the complex theme of the neurobiological basis for woodcarving, the present study proceeds with the discussion one part at the time. This is the reason for developing a series of articles, each exploring different issues.

Cognition

Cognition includes all mental processes, described as "the total output of the cerebral cortex" (Mason, 2011, p. 284). The cerebral cortex is a part of the forebrain and the CNS, and is visually recognized as grey matter. This means that cognition is a very broad term for activities of neurons participating in thinking, motivation, emotion, perception, motor planning, and executive functions, such as when making deliberate choices of actions. Although cognition is a central part of the woodcarver's experience when working with wood, this does not mean that the woodcarver is necessarily aware of it. Only some of the activities that go on in our neural system are brought to our attention. Most of the activity takes place without our having any conscious control over it. Some of it could be consciously recognized, but is not. Other information is voluntary, deliberate, and sometimes even brought to our attention in a way that can be identified and named by words. For a signal to be recognized by or processed by us—for example, the sensation of green wood under our fingertips—it must travel all the way from our fingertips in the outer regions of the PNS and into the cerebral cortex. On its way there, the signal moves through a series of synapses, loops, and multiple circuits, and could end in many places at once.

Woodcarvers and researchers studying woodcarving often use the term "intuitive" or "spontaneous" to describe some of the carver's actions. In my previous study, I used the term "preconscious" (M. Gulliksen, 1997), which is somewhat problematic, as it also suggests a timeline or something that happens prior to consciousness. However, as Merleau-Ponty (1962) also emphasized, intuitive ideas or spontaneous actions do not necessarily occur on their own or without an obvious, preceding reason. We may simply fail to discern the reason. Mason (2011) explains it like this: "[Y]our stomach grumbled and you became aware of being hungry. In the case of neuronal firing, we do not have the luxury of being able to ask the neuron why it fired, as we can ask ourselves why we moved to the kitchen. Therefore, we tend to label activity and behavior 'spontaneous' when the precipitating reason for neuronal activity or behavior is not clearly evident. A cortical circuit that begins to fire 'out of the blue' may in fact be responding to activity elsewhere in the brain. Similarly, an original thought that occurs to us 'out of the blue' may in fact be a response, at some delay, to a previous event" (Mason, 2011, p. 285).

Perception is the part of the sensory experience where we become aware—the part of woodcarving where the carver registers what is happening. What comes to our attention is to some extent dependent on the thalamus, a component of the CNS situated between the cerebral cortex and the midbrain. The thalamus is the place where sensory input (which changes sides when entering the spinal cord) synapses to neurons in the cortex. In the thalamus, the signals coming in are translated to a rhythm the cortex can understand, and from there, they are transmitted to the designated parts of the cortex. The thalamus therefore both translates and relays information; it can also "pump up the volume": "In burst mode, thalamic neurons fire a batch of action potential upon receipt of an action potential […] to 'awaken' the cortex or to increase attention to a particular stimulus feature." (Mason, 2011, p. 280). This is a necessary function for mammals, as it allows a rapid change in behavioral state if, for example, a predator comes at us or we burn our hand. This function could explain why some information suddenly captures our attention—for example when a cut flows "just right" down the shape of the wood, and it informs the carver that the shape is right and the work is finished.

The thalamus also influences where we actively turn our attention. "Thalamic attention" (Mason, 2015) is the term used for our projections or our preconceptions of what we see. To some degree, we see, hear, smell, touch, and so forth what we expect to encounter. Mason explains this, using vision as an example (2011). The primary visual cortex (V1) only receives information from the retina of the eye through the thalamus, which translates the signals so they can be understood by the V1. The same nerve in the thalamus, however, also receives information from the V1 and the brainstem as well, informing us about where we are and what we should expect to see. This information from the V1 and the brainstem is huge. In terms of quantity alone, the information from them outweighs the information from the retina. However, the quality is another matter, and the information from the retina is more important for the thalamic synapse than the other information. Nevertheless, this feed-forward projection of the information that is sensed and later perceived means that the cerebral cortex both receives and influences information from the thalamus (Mason, 2011, p. 284). For the experienced woodcarver, this could mean that visual, aural, and, in particular, tactile sensitivity can be used to identify notches and smaller indications of imperfections in the wood, which must be taken into account when making the next cut. The skilled woodworker can discern by a soft knock and light touch exactly how dry a piece of wood is and estimate how flexible it will be, its cell structure, and what types of tools would be needed to carve it. At the same time, the carver could easily overlook information outside the scope of his or her attention at the given moment—for example, a section of the bowl not yet finished and to be dealt with tomorrow. Moreover, that attention could be used to register an irregular pattern of woodchips on the floor, indicating where a dropped knife is. Another term for such experience-dependent attention is "perceptual habits" (Mason, 2015).

This process of thalamic attention is a crucial component in memory. Perceptual habits develop through experience; they are learned and stored as memories, generating measurable traces in the brain. For the woodcarver's experience of embodied making, the memory formation and awareness are linked together, as they are for every other mammal experiencing any and all information. This topic has been discussed from many different perspectives. A recent example examines the importance of background knowledge and what is available for the working memory of a designer in the design classroom (Trogu, 2015); an interdisciplinary and pragmatic approach to awareness as a part of praxis can be found in the book *On becoming aware* by Varela et al. (2003). In this book, the authors draw on neuroscience, philosophy, and phenomenology to explore the experience of becoming aware, from a first-person perspective.

To the woodcarver, it is indeed relevant to ask: Why does she focus on one part of the forms? Why does she choose one tool over another? Several accounts discuss how the eye and hand of the artist or artisan are particularly trained to see certain things that a novice cannot see or feel. Mueller, Winkelmann, Krause, and Grunwald (2014) provide a potentially relevant example of such a trained perceptual habit. They report that manual therapists who have been practicing for a long time have better haptic perception skills and thus a more nuanced and attentive active touch than inexperienced manual therapists. An interesting finding from this study is that the experienced manual therapists do not have better passive skill—tactile perception—than the inexperienced ones. Using deliberate practice with haptic perception to both diagnose and treat patients has thus left the experienced manual therapists better able to discern and become aware of haptic information, although this has not influenced their tactile abilities. This indicates that haptic and tactile perception skills are different versions of skills, capable of developing separately. This is an example of what makes such studies useful for expanding, nuancing, and/or supporting current phenomenological, descriptive, and interpretive research. As the woodcarver, in many aspects, has a need for haptic perception as the manual therapists do, this raises the questions whether studies of woodcarvers would yield similar results, namely that they too develop the skill of a particularly attentive active touch, learned and stored as memories.

Neuroplasticity and neural circuits

In a neurobiological context, such activity-dependent changes in brain function can be registered and measured by various means, such as the increase of blood flow to certain areas. This neuroplasticity, or activity-dependent plasticity (Purves et al., 2012), is caused by experience. If more information travels a particular path, more synapses between neurons are formed (synaptic plasticity), new neurons can be made (neurogenesis), and inherent properties of the neuron can potentially be changed (inherent plasticity), as Seghal, Song, Ehlers, and Moyer Jr (2013) suggest. If fewer signals travel, the path can wither and even disappear. This plasticity partly explains why every brain is slightly different from any other, as our experiences are important determinants of the development of our own brain.

A famous example of experience-dependent plasticity is a study of taxi drivers in London, who had an increased number of synapses in an area of the forebrain related to spatial organization (Maguire et al., 2000). Another classic example is the study showing differences in the cortex devoted to the right and left hands of musicians playing stringed instruments

(Elbert, Pantev, Wienbruch, Rockstrosh, & Taub, 1995). When doing so, the two hands perform quite different tasks, making the right and left areas of the brain develop differently. A consequence of such a plasticity could be that the brain of the experienced woodcarver might be expected to be especially tailored to process the type of signals needed in his or her carving. For the purposes of this article, one of many relevant questions would therefore be where such possible changes could occur, which processes are affected, and what this could entail for the carver's experience. In the first of my articles on this topic, changes in the cerebellum were suggested (M. S. Gulliksen, 2015c), mainly related to motor movement and thus also to intrinsic motor memory.

Neuroplasticity is, as such, a basic component of learning and memory. Learning in neuroscientific terms is referred to as "the process by which new information is acquired by the nervous system and is observable through changes in behavior" (Purves et al., 2012, p. 695). While memory "refers to the encoding, storage, and retrieval of learned information" (Purves et al., 2012, p. 695), both memory and learning are parts of the limbic system, defined as "parts of the brain involved in emotional processing, learning and memory" (Mason, 2011, p. 266). Limbic structures communicates through of one of the most important circuits in our brain, the Papez circuit, which links together distinctly separate areas of the brain as a pathway. The woodcarver's embodied making consists of acquiring, processing, and storing new information. Memory is therefore probably a central neurobiological function in this activity-dependent plasticity, and a basis for this experience.

Memory

Woodcarvers often report vivid and complex memories of their carving. They describe the smell of the wood, the position of their body, how the green wood feels damp, or their emotional state, as in the following example:

> The bowl fits into my own shapes. It is safe in my lap now, in warm, round crannies. The rough inner bowl feels wet and tepid to my left hand. Dampness seeps through my sleeve at the elbow. Right hand outside. Smooth and sandy, small, small bumps after the scraper and sanding paper. Tiny precision cuts with the gauges. Hands moving in circles. Protective. Wet, fresh smell of green birch tickles my nose. Easy itch inwards. Next day, I took it out after a thorough sanding and a spray of water. Surface like fine suede leather. Soft, furry, and slick. Slide my fingertips carefully over and feel a gentle and silent tickle (M. Gulliksen, 1997, p. 76, my translation).

In this sample text, many different types of memory can be discerned. Neurobiologists refer to (at least) six types of memory, and their distinct cellular elements and functional cycles give some indication of why these memories could be important to carvers.

Immediate memory, working memory, and variations of long-term memory

Neurobiological description of the memory distinguishes between immediate memory, working memory, and long-term memory. Long-term memory could be implicit (non-declarative) memory or declarative memory.

Immediate memory is the instant fleeing thought, when current experiences are held in the mind for fractions of seconds. Researchers believe that these immediate memories have a very large capacity and consist of a variety of semi-independent "memory registers," which are most likely distinctly different for each sense modality (Purves et al., 2012, p. 696). Working memory is the memory involved in being in the here and now, or keeping information in mind for seconds and minutes. Dietrich (2004) describes it as "the ability to process information online. It is a monitoring system of ongoing events that temporarily keeps in mind information that is relevant to the situation, so that one can 'work' with it" (p. 1013).

The carver making wooden objects continuously experiences the making process through both immediate and working memory. This may include knowing what I did a second ago, where I put the knife just now, what I need to do next when finishing the current cut with the gauge, or non-carving-related thoughts, such as what to buy for lunch. A typical example is constantly repeating a phone number while looking for a pen to write it down (Mason, 2015). Working memory seems to be a necessary ingredient in cognitive flexibility, and its role as continuous information processor probably makes it a central component in generating consciousness and a prerequisite for creative thinking (Dietrich, 2004, p. 2013).

Long-term memory has two main variations: implicit memory and declarative memory. Implicit memory is a collective term for the many types of memory that we cannot deliberately and explicitly recall—for example, motor memory of how to hold the carving knife, associations, priming cues, and emotional memory, such as the carver feeling comfortable in the wood shop. Procedural memory is also a type of implicit, non-declarative memory (Mason, 2011; Purves et al., 2012). To the woodcarver, implicit memory is a large part of the making experience. This could involve such memories as those of the pungent smell of juniper compared to the fresh and crisp scent of birch, and the feeling of pine sap versus willow sap under warm fingers. Also, the implicit perceptual memory lets a skilled carver register where the form needs more work or recognize patterns in the curled planer cuts on the floor that allow her to locate the exact position of a dropped knife that is hidden from view—a possible developed perceptual habit, a trained, directed visual attention. In the example presented above, the body experience of the gauge sliding "just right" down the wood fiber is combined with a recollection of previous experiences: how resistance feels in the arms, and how it should feel when the shape is beginning to come together. The anatomical and functional elements of this motor memory are related to voluntary movement and sensory input, monitored in the cerebellum (M. S. Gulliksen, 2015c). As with long-term memory, such implicit memories could last a lifetime (Mason, 2015).

Declarative memory is the type of long-term memory that can be remembered explicitly. It consists of two main types: episodic memory and semantic memory. Episodic memories are rich and varied, comprising a suite of sensory experiences and details, some of which are also implicit memories. It is possible to "dive back into" them (Mason, 2015) and recall lesser details, and even implicit memories, for example whether you were comfortable at the time or how your hand feels sore after a full day of carving. Semantic memories, on the other hand, are our recollection of facts, definitions, and told stories memorized. Episodic memories could be turned into semantic memories if re-told many times as a story. The woodcarver uses declarative memory in many ways when carving: The names of tools, types of wood, other craftsmen, memories of previous carving situations, and the intended plan of the work, which tells her which section to carve first or later, are stored as declarative memories.

Changing working memory into long-term memory

In order to change working memory into long-term memory, several circuits and areas in the brain are needed. For example, a decision must be made about what is and is not stored in long-term memory. Forgetting is as important as remembering in order for a mammal to function. Only information considered important enough is stored; this indicates that it is likely that the thalamus is involved (Mason, 2011, p. 284ff). Memories are stored as engrams or "the physical embodiment of any memory in neuronal machinery," and the general consensus, according to Purvis et al. (p. 698), is that these engrams are related to the efficiency of the synapses. However, some new studies, like the experiment of Seghal et al. (2013), indicate that the neurons themselves also store information.

This process for storing or consolidating memory varies between the types of memory. Implicit and declarative memories are not stored by the same brain circuits. Indeed, not even the different varieties of implicit memory are stored using the same processes. For example, the cerebellum would be involved in motor memory (M. S. Gulliksen, 2015c; Mason, 2011, p. 538), and the amygdala would be involved in storing emotional memory (Mason, 2011, p. 288). The amygdala contributes to several functions linked to our emotional understanding of our social environment—for example, decoding another person's facial expressions as registering fear. Because of the amygdala's contribution to storing emotional memories, we remember evocative memories with strong emotions and great sensory input—experiencing a fire in your house or cutting your finger—more strongly than non-evocative memories (Mason, 2011, p. 289; 2015). Neuropsychologists use this particular knowledge in post-traumatic stress disorder (PTSD) therapy. Individuals suffering from PTSD have an overactive amygdala, which leads to a high level of emotions in traumatic situations. Treatment requires the patients to relive their traumatic memories while repressing their emotional side with drugs or other means, so that the memory is restored but with less fear attached to it.

Changing working memory into long-term declarative memories, both episodic and semantic memories, involves the hippocampus. The hippocampus is a section of the cerebral cortex, situated in the medial temporal lobe of each side, and is thus a part of the three-layered cerebral cortex (Mason, 2015) (Figure 4).

Figure 4. The hippocampus. Image credit: https://en.wikipedia.org/?title=Hippocampus

Different areas of the hippocampus are linked to different types of memory; for example, spatial memory appears to be relayed by the posterior hippocampus. The study that found experience-dependent plasticity in the brain of taxi drivers, mentioned above, also found differences in this section of the hippocampus: The size of the posterior hippocampus co-varied with the number of months of taxi-driving experience of the drivers (Maguire et al., 2000; Purves et al., 2012, pp. 707-708).

As implicit memories are not stored by the same brain circuits that turn working memory into explicit memory, persons suffering amnesia may remember them, even though much else is lost. This may be observed in older amnesic people, who may not remember their children's names or how to read, but could be dancing, carving, or knitting perfectly (Mason, 2015).

Storing and recalling memories

Declarative memories are stored in specific, designated areas of the neocortex, the six-layer section of the cerebral cortex (Mason, 2015). The hippocampus relays the converted new memories to the neocortex. Both semantic and episodic memories are stored and can be retrieved from there.

Retrieving memories from the neocortex is a process that differs noticeably between semantic and episodic memories: whereas semantic memories can be pulled out directly from the neocortex, episodic memories need to be shipped back to hippocampus before they can be accessed (Mason, 2015). As episodic memory is recalled with the help of the hippocampus, it follows that it is re-stored or even relived each time it is recollected. This forms a circuit of storing and re-storing of the experienced episodes, permitting the memory to be changed each time (Mason, 2015).

For the woodcarver spending many hours in the workshop, old memories will continually be supplemented and merged with new memories. For example, one day when I was carving outside my workshop (Figure 5), I remembered episodes of carving outdoors in a medieval market four years before. I remembered the particular event in my childhood when I was alone in my parents' workshop and cut my thumb, how it bled, how I ran to get a towel and to track down my mother. At the same time, I remembered for whom I was making this bowl now, and why. It all melted together, filling my here-and-now experience with ghosts from the past, present, and future.

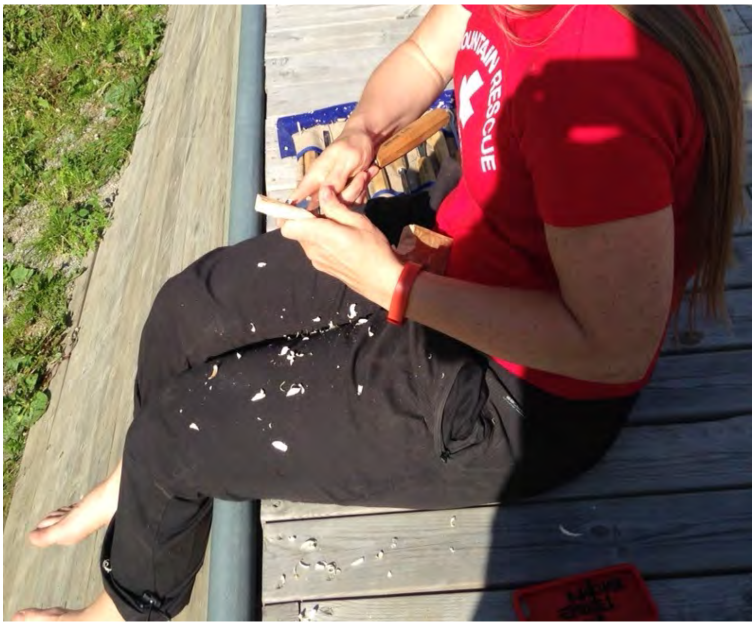


Figure 5. Making the aspen bowl in Figure 3 while writing this article (2015).

Tentative ideas of where to look for a neurobiological basis for creative cognition and embodied making

This article has discussed the role of the hippocampus in the working memory, as well as long-term memory storage and retrieval when engaged in embodied making. Neurons, neural communication, neural circuits, and the neural basis for cognition and awareness have been briefly introduced. Current neuroscientific knowledge has been used to explain the difference between cognition, defined as the total output of the cerebral cortex, and awareness, the part that we perceive and become aware of. Moreover, the difference between spontaneous (but not random) and deliberate states of mind has been discussed. The role of thalamic attention, and how touch and other sense modalities are trained to be particularly attentive through practice has been emphasized, and the relatively small amount of information that comes into a person's awareness, how our preconceptions influence our perceptions, and how perception as such is a form of interpretation has been problematized.

Most emphasis has been put on describing the neural basis of immediate memory, working memory, and variations of long-term memory—in particular, implicit motor and emotional memory, semantic memory, and episodic memory, along with information about how working memory is stored and retrieved. I have referred to specific studies of memory and learning that have documented physiological changes (i.e., neuroplasticity) in the hippocampus. Experience-dependent neuroplasticity is a crucial function in our ability to learn, at least according to the neurobiological definition of learning: "the process by which new information is acquired by the nervous system and is observable through changes in behavior" (Purves et al., 2012, p. 695). A particular point of interest is the difference between storing and recollecting declarative semantic versus episodic memory. Whereas semantic memories, such as facts and numbers, are recollected directly from their long-term storage in the cerebral cortex, episodic memories are remembered through the hippocampus—the same area of the brain that stores and re-stores memories. This means that each time an episodic memory is remembered, it is re-remembered and re-stored, and could therefore be subject to change by the new "here-and-now" experience. When looking for a neurobiological basis for creative cognition and embodied making, the neural circuit in the hippocampus that retrieves, stores and re-stores memories could be a central key.

Here I will mention three tentative ideas that could be relevant for further exploration based on this neural circuit of memory storage and retrieval.

First, as declarative episodic memories are always complex and may be linked with implicit motor and emotional memories, the many layers in these memories—sensations, emotions, motor memories—could suggest a neural basis for the woodcarver's ability to recall and relive making experiences in great detail, and perhaps even explain why such memories are vivid and rich in detail and meaning for the carver.

Second, the neural circuit in the hippocampus may provide another key to understanding how the woodcarver's sensory–motor and cognitive experiences "melt together" in the negotiations between maker and material. This circuit of memory storage runs in parallel with the overload of sensory input and motor output of the cerebellum (M. S. Gulliksen, 2015c), only some elements of which come to our attention. This may serve to expand current descriptions of the making experience as intense negotiations and interactions between maker and material. This supports and expands the previous phenomenological descriptions of making processes (M. Gulliksen, 1997). The making experience is not necessarily something we are aware of in every aspect, but it could nevertheless direct our attention toward something in a way that I, in my previous study, would have called preconscious.

Third, for a woodcarver spending a great deal of time carving and negotiating with raw materials, the continuous circuit of retrieving and re-storing memories combines the overload of sensory input (M. S. Gulliksen, 2015c) with emotions of identity. The carving experience includes who I am, who I was, and who I could be. This continuous circuit could create the experience of being here-and-now, which makes it more difficult to discern from what was and what will be. The intense experience referred to by woodcarvers of "being-here" (M. Gulliksen, 2001; M. S. Gulliksen, 2014) could then be understood not as an independent event or an independent experience of immediacy, but as an experience of being here, now, as the result of the carver's previous experiences and projections for the future.

To take another example:

Figure 6. A five-year-old boy making a bowl in linden wood, at a medieval market (2011). Parent permission to publication of photo is obtained.

The boy in Figure 6 is overcoming resistance. He is totally immersed in his carving, undisturbed by me taking his photo. He has just mastered this spoke shave, and has a good grip on the bowl with his toes. As he is dressed only in his ninth-century-style linen tunic, his bare legs can feel the soft, wet grass underneath him, and he is exploring the shape with his hands, toes, body position, eyes, and smell. He is negotiating the resistance in his bowl. His cerebellum is monitoring sensory input and gradually adjusting the motor output to keep the angle of the spoke shave just right. When perfect curls of the wet wood emerge from the sharp knife, he smiles and hums. The joy of controlling this new tool and making a bowl of his own for the very first time makes this situation emotional. Today, four years later, he still remembers it. He sometimes mentions this particular episode and other similar ones. He asks if he can make something, and, when given the spoke shave, his hands know what to do.

The five-year-old boy's awareness was at the time tuned into his making, totally focused, but probably not deliberately reflecting on what to do. As a maker, his working memory negotiates with the material in an associative way, turning his attention toward what is brought to his attention. This is drifting and unsystematic, yet it is fully controlled by his attentive and seeking haptic perception. As such, he could possibly be evincing a creative cognitive state of mind (Lopata, 2014), in which the "sequence of thoughts manifesting itself in consciousness is more chaotic, permitting more 'loosely connected' associations to emerge" (Dietrich, 2004, p. 1017). Different areas of his brain fire at the same time, simultaneously and/or causally (Friston, 2002), causing him to sense, perceive, respond, and act together with his environment. Such associative working memories are turned into associative, episodic long-term memories by the hippocampus, which be recalled by the hippocampus through similar instances of associations.

It is therefore probable, or, as Mason would have said, a current best guess (Mason, 2011, p. 22), that, through this experience (and other similar experiences), his hippocampus has changed slightly, as a response to its contribution to making memories, in the same way as the hippocampus of the musicians in Elbert et al.'s study (1995) or the taxi drivers in Maguire et al.'s study (2000) changed. As he grew older and continued these activities, his attentive active touch could also be modified, like that of the manual therapists in the study of Mueller et al. (2014). An implication for further research would therefore be to develop a strategy for studying short- and long-term consequences of making activities, in order to explore further if this is the case.

Tentative conclusions - ideas for further exploration

This article aims to understand parts of the embodied making experience, drawing on neurobiological knowledge. It arose from phenomenological descriptions of woodcarving in a previous study (1997), in which I described the experience of carving as a negotiation in a preconscious and conscious state of mind, and "a perceptual field opening up to the body" (Gulliksen, 2001, pp. 4-5). The current article's exploration of the maker's cognition and attention, through discussion of the central aspects of the neurobiological basis for experience, memory, and, specifically, the relationship between working memory and long-term memory, has expanded and moderated the conclusions from the previous study. The neurobiological knowledge supports the descriptions of embodied making, both from my previous study and from similar accounts (Groth, 2015; O'Connor, 2005), and allows for enhanced understanding and explanation of the biological function behind this.

The ideas for future studies, presented above, are necessarily tentative and speculative, as they are developed only to open up a small piece of neurobiological knowledge relevant for understanding the woodcarver's experience. However, they may become a starting point for future work that aims to develop possible interdisciplinary and researchable hypotheses.

In the future, it could be possible to build on this description and develop a research-based hypothesis on the activity-dependent plasticity of the woodcarver's hippocampus. This could possibly be designed to replicate or discover similarities to the studies of the hippocampus plasticity of musicians (Elbert et al., 1995) and taxi drivers (Maguire et al., 2000). Such a study could, for example, examine experienced woodcarvers compared to non-experienced woodcarvers, or study the changes in people's brains caused by an intervention of carving in green wood.

Furthermore, it would be interesting to study whether the perceptual habits in haptic perception of experienced carvers are more accurate than those of inexperienced carvers, and to replicate the study of the manual therapist (Mueller et al., 2014) in this context. It could even be relevant to design a study of the possible changes in thalamic attention in experienced versus non-experienced carvers, or the changes caused by learning to carve or actively carving over a period of time.

Such studies could reveal more about the woodcarver's experience and its consequences. This could be crucial knowledge in today's society. As many of us who carve are aware, the activity of carving becomes rarer every day. In schools, at least in Norway, few do it. Although phrases such as "active learning" and "experiential learning" are much heard in discussions about education, policymakers and school principals seem to set little store by them in practice. The focus of attention in schools is the so-called core subjects. Consequently, decision makers often regard carving and similar activities as pleasant but not very important (Bamford, 2006, 2012). It thus seems that compelling current and scientific knowledge on the benefits of making activities does not influence a school's core curriculum. There are probably a complex set of reasons for this. However, there seems to be a tendency for policymakers and school principals to prefer certain types of research-based knowledge over other types. Given the new methodologies and techniques available in neuroscience, it may be possible to support previous phenomenological, descriptive, or reflective research findings with findings from transdisciplinary studies. If successful, this could possibly generate new and communicable knowledge that policy makers could understand, appreciate, and give priority to in schools.

Worldwide, there is a demand for skilled hands in various occupations, ranging from electricians, plumbers, and carpenters to robotics constructors and machine operators. Likewise, surgeons, veterinarians, researchers working in advanced labs, and other highly educated professions require nimble and skilled hands. Developing more knowledge about such skills and how they are learned is crucial. If research on the actual neurobiological changes in children and adults engaging in embodied making could explain whether and how making contributes significantly to developing these valuable skills, it could possibly lead to new approaches to learning in schools and elsewhere. Specifically, understanding the woodcarver's experience and the process of embodied making in green wood could therefore demonstrate why woodcarving could be an important activity in which we should engage in the twenty-first century.

Marte S. Gulliksen
Professor, PhD
University College of Southeast Norway, Faculty of Art, Folk Culture and Teacher Education
Email address: marte.gulliksen@hit.no

References

Ansari, D., & De Smedt, B. (2012). Neuroeducation: A critical overview of an emerging field. *Neuroethics* (5), 105–117.

Bamford, A. (2006). *The wow factor: Global research compendium on the impact of the arts in education*. Münster: Waxmann.

Bamford, A. (2012). Arts and cultural education in Norway 2010-2011. Retrieved 10.06.2016 from Nasjonalt senter for kunst og kultur i opplæringen: http://www.kunstkultursenteret.no/sites/k/kunstkultursenteret.no/files/1f0ba571783fe8dc31a13ac76d5f196a.pdf

Basset, D. S., Yang, M., Wymbs, N. F., & Grafton, S. T. (2015). Learning-induced autonomy of sensorimotor systems. *Nature Neuroscience, 18*, 744–751. doi:10.1038/nn.3993

Bergson, H. (1988). *Matter and memory*. New York: Zone Books.

Bresler, L. (2004). *Knowing bodies, moving minds: Towards embodied teaching and learning*. Dordrecht: Kluwer.

Crawford, M. (2009). *The case for working with your hands*. London: Penguin.

Csikszentmihalyi, M. (1996). *Creativity: Flow and the psychology of discovery and invention*. New York: Harper Collins.

Dahl, J. S., & Dahl, A. S. (2015). The new wood culture: Part one – Wood is not steel. Retrieved 10.06.2016 from http://woodspirithandcraft.com/

De Smedt, B., Ansari, D., Grabner, R. H., Hannula-Sormunen, M., Schneider, M., & Verschaffel, L. (2011). Cognitive neuroscience meets mathematics education: It takes two to tango. *Educational Research Review* (6), 232–237.

Dietrich, A. (2004). The cognitive neuroscience of creativity. *Psychonomic Bulletin & Review, 11*(6), 1011–1026.

Elbert, T., Pantev, C., Wienbruch, C., Rockstrosh, D., & Taub, E. (1995). Increased cortical representation of the fingers of the left hand in string players. *Science, 270*, 305–307.

Fredriksen, B. (2013). *Begripe med kroppen. Barns erfaringer som grunnlag for all læring*. Oslo: Universitetsforlaget.

Friston, K. (2002). Functional integration and inference in the brain. *Progress in Neurobiology, 68*(2), 113-143. doi:http://dx.doi.org/10.1016/S0301-0082(02)00076-X

Goguen, J. A., & Myin, E. (2000). *Art and the brain. Part II*. Thorverton: Imprint Academic.

Goswami, U. (2006). Neuroscience and education: From research to practice? *Nature Reviews Neuroscience, May*, 406–413. doi:10.1038/nrn1907

Groth, C. (2015). Emotions in risk assessment and decision making processes during craft practice. *Journal of Research Practice, 11*(2), 1-21. Retrieved 10.06.2016 from http://jrp.icaap.org/index.php/jrp/article/view/502/441

Gulliksen, M. (1997). *Det skapende møtet: En teoretisk og en praktisk estetisk studie av personens møte med materialet i den skapende prosessen.* (Hovedfag), Høgskolen i Telemark, Notodden.

Gulliksen, M. (2000). Om estetikken i møtet med materialet i den skapende prosessen. *Arabesk – Tidsskrift for Musikk og Dans, 2000/2.*

Gulliksen, M. (2001). The creative meeting: A discussion over the aesthetic elements in the creative process. In C. Nygren-Landgärds & J. Peltonen (Eds.), *Visioner om slöjd och slöjdpedagogik* (Vol. B:10/2001). Vasa: NordFo/Åbo Universitet.

Gulliksen, M. S. (2014). *Teaching and learning embodied making*. Paper presented at the Technological Learning & Thinking symposium, July 14th 2014, Vancouver.

Gulliksen, M. S. (2015a). Embodied making and learning. Retrieved 10.06.2016 from https://www.usn.no/embodied-making-and-learning/category26847.html

Gulliksen, M. S. (2015b). The glimpse of the forest: Exploring visual attention through knowledge of the brain and practice of iPhone photography. (manuscript in preparation)

Gulliksen, M. S. (2015c). Why making matters: An exploration of neurobiological perspectives on wood carving. Paper presented at Eksig 2015: Tangible Means – experiential knowledge through materials, Kolding, Denmark.

Gulliksen, M. S. (2016a). *Challenges and possibilities in an integrative applied research study of how embodied making may contribute to learning.* Paper to be presented at Make it NOW conference, 27-30. September 2016, Rauma, Finland

Gulliksen, M. S. (2016b). Why making matters: Developing an interdisciplinary research project on how embodied making may contribute to learning. Paper to be presented at DRS2016, 27-30 June, 2016, Brighton. Retrieved 10.06.2016 from http://www.drs2016.org/193

Hass-Cohen, N., & Carr, R. (Eds.). (2008). *Art therapy and clinical neuroscience*. London, Philadelphia: Jessica Kingsley Publishers.

Ingold, T. (2013). *Making: Anthropology, archaeology, art and architecture*. London: Routledge.

Juelskjær, M., Moser, T., & Schilhab, T. (2008). *Learning bodies*. Aarhus: Aarhus University Press.

Karlsen, B. (1994). *Det stoffliges estetikk*. Notodden: Telemark lærerhøgskole.

Lopata, J. A. (2014). Creativity as a mental state: An EEG study of musical improvisation. (PhD Monograph), London, Ontario, University of Western Ontario.

Maguire, E. A., Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S. J., … D., Frith. C. D. (2000). Navigation-related structural change in the hippocampi of taxi drivers. *Proceedings of the National Academy of Sciences, 97*, 4398–4403.

Mason, P. (2011). *Medical neurobiology*. Oxford, New York: Oxford University Press.

Mason, P. (2015). Understanding the brain: The neurobiology of everyday life. Lectures 1–10. Chicago: The University of Chicago.

Merleau-Ponty, M. (1962). *Phenomenology of perception* (C. Smith, Trans.). London: Routledge.

Michl, J., & Dunin-Woyseth, H. (2001). *Towards a disciplinary identity of the making professions: The Oslo millennium reader*. Oslo: Oslo School of Architecture.

Mueller, S., Winkelmann, C., Krause, F., & Grunwald, M. (2014). Occupation-related long-term sensory training enhances roughness discrimination but not tactile acuity. *Experimental Brain Research, 232*(6), 1905–1914.

O'Connor, E. (2005). Embodied knowledge. The experience of meaning and the struggle towards proficiency in glassblowing. *Ethnography, 6*(2), 183–204. doi:10.1177/1466138105057551

Osborne, E. J. (Producer) (2014, 01.06.2015). How to make a wooden spoon. *TedXBrighton*. Retrieved from http://tedxtalks.ted.com/video/How-to-Make-a-Wooden-Spoon-|-EJ;search%3Aej%20osborn

Østerberg, D. (Ed.) (1995). *P. Bourdieu: Distinksjonen – en sosiologisk kritikk av dømmekraften*. Oslo: Pax forlag.

Purves, D., Augustine, G. J., Fitzpatrick, D., Hall, W. C., LaMantia, A. S., & White, L. E. (Eds.). (2012). *Neuroscience.* (4th ed.). Sunderland, MA: Sinauer Associates.

Rosa, M. J., Daunizeau, J., & Friston, K. J. (2010). EEG-fMRI integration: A critical review of biophysical modeling and data analysis approaches. *Journal of Integrative Neuroscience, 9*(4), 453–476.

Rosch, E., Thompson, E., & Varela, F. J. (1991). *The embodied mind: Cognitive science and human experience*. Cambridge, MA: MIT Press.

Seghal, M., Song, C., Ehlers, V. L., & Moyer Jr, J. R. (2013). Learning to learn: Intrinsic plasticity as a metaplasticity mechanism for memory formation. *Neurobiology of Learning and Memory, 105*, 186–199.

Seitamaa-Hakkarainen, P. (2015). What neuroscience can tell us about skill learning in craft - The promise of cognitive neuroscience in design studies. Paper presented at the LearnXDesign2016 – CUMULUS and DRS Conference, Chicago.

Seitamaa-Hakkarainen, P., Huotilainen, M., Mäkelä, M., Groth, C., & Hakkarainen, K. (2014). The promise of cognitive neuroscience in design studies. Paper presented at the DRS 2014, Umeå, Sweden.

Simons, R. L., & Klopack, E. T. (2015). Invited address: "The times they are a-changing. Gene expression, neuroplasticity, and developmental research." *Youth Adolescence* (44), 573–580.

Streeck, J., Goodwin, C., & LeBaron, C. (2011). Embodied interaction in the material world: An introduction. In J. Streeck, C. Goodwin, & C. LeBaron (Eds.), *Embodied interaction: Language and body in the material world*. Cambridge, UK: Cambridge University Press.

Trogu, P. (2015). Working memory and background knowledge: Cognitive science in the design classroom. *FORMakademisk, 8*(1), 1–17.

Varela, F. J., Vermersch, P., & Depraz, N. (2003). *On becoming aware: A pragmatics of experiencing*. Amsterdam, Philadelphia, PA: J. Benjamins.

Wall, M. (2014). How neuroscience is being used to spread quackery in business and education. Retrieved from https://theconversation.com/how-neuroscience-is-being-used-to-spread-quackery-in-business-and-education-30342

Western University (2014). Education–Neuroscience Symposium: Minds on minds. London, Ontario: Western University.

Winner, E., Goldstein, T. R., & Vincent-Lancrin, S. (2013). *Art for art's sake? The impact of arts education*. Newcastle upon Tyne: OECD Centre for Educational Research and Innovation.

Zaidel, D. W. (2005). *Neuropsychology of art: Neurological, cognitive and evolutionary perspectives*. Hove: Psychology Press.

http://dx.doi.org/10.7577/formakademisk.1461

Maarit Mäkelä

Personal exploration: Serendipity and intentionality as altering positions in a creative process

Abstract

Artists and designers have recently begun to take an active role in contextualising the creative process in relation to their practice. Thus, understanding how the creative mind proceeds has been supplemented with knowledge obtained inside the creative process. In this way, the spheres of knowledge, material thinking and experience that are fostered through creative work have become entangled and embedded as elemental parts of the research process. This article is based on documentation and reflection of the author's creative practice in contemporary ceramic art at the beginning of 2015. The article discusses how the creative process proceeds by alternating between two positions: serendipity and intentionality. By describing the different phases of the process, it reveals the interplay between the diverse range of activities and how these gradually construct the creative process.

Keywords: ceramics, creativity, documentation, reflection, personal knowledge, walking

Introduction

The exploration of knowledge, partly through making, has recently brought a new dimension to research in the creative fields. In addition to producing artefacts, practitioner-researchers also document, reflect and contextualise their related creative process as well as its outcomes (Mäkelä & Latva-Somppi, 2011, p. 39). In this way, the spheres of knowledge, material thinking and experience that are fostered through creative work have become fundamentally entangled (Mäkelä & O'Riley, 2012, p. 8) and embedded as elemental parts of this form of research. Currently, these kinds of research approaches – relying fundamentally on researchers' subjective knowledge – are developed under a wide range of trends, such as practice-based, practice-led and artistic research, as well as some sub-trends that are embodied within the notion of constructive design research (Koskinen, Zimmerman, Binder, Redström, & Wensveen, 2011). These trends support the idea of a practitioner-researcher who is, on one hand, the executor or facilitator of the creative process and, on the other hand, the one who reflects on the entire process:

> The whole issue is … about the self-reflective and self-critical processes of a person taking part in the production of meaning within contemporary art, and in such a fashion that it communicates where it is coming from, where it stands at this precise moment, and where it wants to go. (Hannula, Suoranta, & Vaden, 2005, p. 10)

Social scientist Donald Schön (1991) discusses the essence of reflective practice and proposes that our knowing is in action, ordinarily in tacit form and implicit in our patterns of action. He maintains that there are two kinds of reflection that take place at different stages of action. The first, reflection-in-action, indicates a process in which practitioners encounter an unusual situation and have to take a different course of action from that which they usually do or originally planned (Schön, 1991, pp. 128–136). The second, reflection-on-action, includes an analytical process in which practitioners reflect on their thinking, actions and feelings in connection with particular events in their professional practice (Schön, 1991, pp. 275–283; see also Mäkelä & Nimkulrat, 2011, p. 2). Artists and designers have recently begun to further explore these ideas in the context of their own practice. In this way, understanding how the creative mind proceeds has been supplemented with the knowledge attained inside the creative process.

To enable this reflection, practitioner-researchers have begun documenting steps relating to their professional practice in diverse ways. In these studies, documentation is used as a research tool for capturing reflection *on* and *in* action (Mäkelä & Nimkulrat, 2011, p. 8). When documenting their creative processes, they consciously reflect on their current experiences during the process (reflection-in-action) and on the documented experiences once the entire process has been completed (reflection-on-action). In this way, documentation can assist in capturing the experiential knowledge in the creative process so that what the practitioner learns from within her practice becomes explicit, accessible and communicable (Scrivener, 2002, p. 25).

Social anthropologist Sarah Pink (2011, p. 271-272) discusses the use of visual recording as a way of representing elements of the experience and the memories and imageries related to it. Furthermore, she observes that there are certain forms of knowledge that cannot be understood simply through observation but instead only by being engaged in a practice per se. The idea has been applied by several practitioner-researchers who have recorded their practical endeavours by means of photographs (e.g. Ings, 2014; Nimkulrat, 2012) and video (e.g. Groth, Mäkelä & Seitamaa-Hakkarainen, 2015). The visual recordings have also included sketches. For example, industrial designer Owain Pedgley (2007, p. 480-481) filled systematically preformatted diary pages in order to capture his own design practice through sketches and written diary notes. According to him, a diary that is allied to reflective practice is well-suited for capturing one's own design activity on a macroscopic level. He encourages the further exploration of whether diaries would also be suitable for illuminating specific subjects, such as creativity and discovery.

In this article, I follow these tendencies and use my own creative practice to gain knowledge, insight and understanding of the creative process. Creative work can be considered an interplay between serendipity and intentionality (Finke, 1996) in the sense that it is based, on one hand, on accidental discoveries and, on the other, on systematic thinking and doing. The leading question of this study is as follows: How does the creative process proceed in alternating between positions of serendipity and intentionality?

The documents gathered during the course of the study – photographs, written diary notes and sketches – serve as representations of the related creative process. In addition, the documentation served as a research tool for capturing my experiences and memories when looking back on the physical actions, embodied experiences and related thoughts that took place during the process. The article begins with a description of how the creative process began to evolve, followed by a description of the different stages of the creative process that took place either at the studio or in the surrounding countryside. The paper concludes with a discussion of how walking came to be an important part of the creative journey that directed the entire process.

The evolving creative process

As a ceramic artist, I am fascinated by the geological features of a given place, including the local soil, rock and sand reserves. These materials create a fundamental base for my art practice. I would even consider their use as a strategy through which I construct meanings embodied in the works. In discussing the connection between aesthetics and ethics, American aesthete Marcia Eaton (1997, p. 361) recommends a conceptual interdependence between these spheres: 'In order to understand morality and thus become a mature moral person, one's action must have both appropriate style and content, and this requires aesthetic skills'. According to Eaton, in this position, neither the aesthetic nor the ethical is prior. Even so, she advocates a role for ethics that defies traditional aesthetics, thus calling for an aesthetics that does not exclude ethical, ecological or environmental concerns (Brand, 1999, p. 5).

Accordingly, political theorist Jane Bennett calls for a deeper understanding and recognition of the linkage between nature, ethics and affect. Through the concept of *vital materiality*, she refers to a force that cannot be separated from matter. A craftsperson, or anyone else intimate with things, senses a force which is manifested as a propensity or tendency trapped in the matter (Bennett, 2010, p. 56). This force has an impact for the creator, and the direction in which it takes her depends on the other forces, emotions and bodies that are present in the process. As a consequence of this, the craftsperson develops a deep understanding of the 'vitality' of a specific material, and this leads to a productive 'collaboration' with it (Bennett, 2010, p. 60; see also Mäkelä & Löytönen, 2015, pp. 179-180). This idea is at the heart of my own artistic practice. I believe that my handling of the earth-based materials invites me into a certain collaboration with them.

Even though my roots are in Finland, the context of this case study is Australasia, where my 2015 artistic practice occurred. The stay preceded a short preparatory trip to New Zealand. During this stay, I collected some samples of the local soil. This was not a planned endeavour but rather an unintentional occurrence that happened during my walks in the local surroundings – the forests and beaches in Auckland (Figure 1). The walks resulted in a collection of tiny gatherings of ochre, yellow sandstone and black sand. The most unique was the black sand as this was something that I had not seen before.

Figure 1: Black sand in Te Henga, Auckland, October 2014. Photo: Maarit Mäkelä.

When I returned to Finland, I put the sand into a ball mill with water, and after 20 hours, this had transformed into a black liquid – a combination of water and powdered sand (Figure 4a). This liquid was one of the few things I took with me when I finally left Finland for my journey, which was to last the entire year of 2015. Only while writing this article did I understand that all of the above-described experiences and experiments were important as they gradually formed the way I proceeded in my work when I arrived in Australasia.

In one of my earlier writings with my co-author Tim O'Riley (Mäkelä & O'Riley, 2012), we introduced the notion of serendipitous moments – the point at which intention and accident collide. We noted that creative practice often entails an amalgamation of things discovered by chance. Commonly, 'these chance occurrences become discoveries through an intentional perception, one that betrays at times an unspoken or tacit intention or, on other occasions, an overt and definable method and goal' (Mäkelä & O'Riley, 2012, p. 10). I consider that my own work as an artist is a dialogue between serendipity and intentionality; it is partly based on experiments and accidental discoveries, partly on careful planning and systematic making.

Encountering the local natural environment

The year started with two months as an artist in residence in Tasmania. I arrived by boat from Melbourne, thus moving from the mainland of Australia to an island. After this, I drove slowly through the island towards the opposite coast where Hobart, and the studio I was going to work in for the next two months, was situated. The drive followed the east coast, and during the journey, I walked in the forests and on the beaches, trying to understand the nature of the land I had arrived in. Just before reaching Hobart, I had a walk on one of the nearby beaches. This walk is recorded in my working diary as follows:

> The bedrock at the northern end of the beach was amazingly yellow, and water had carved its artworks in it. The earth was easily eroded, and some pieces of soil had fallen onto the beach. The pieces formed huge boulders that the water had sculpted. Some of the stones had broken further into smaller pieces. When I touched one of them, it was evident that I could easily crush it into powder. Thus, I decided to take some small pieces of the stone with me. (Working diary 26 January 2015)

In addition to the yellow sandstone (Figure 2a), I gathered small red stones from the beach. Together with the black sand, these formed the collection on which I based my first material experiments.

Figure 2: (a) Yellow sandstone in Orford, January 2015; (b) gathering ochre samples on Bruny Island, February 2015. Photos: Pertti Mäkelä.

The first encounters with the local natural environment had a fundamental influence on my evolving creative practice. On one hand, I was impressed by it, especially the earth-based materials such as ochre and sandstone. On the other hand, I was fascinated by the important role the land played in the local history, that is, the history of the Aboriginal people who had lived in the area for at least 40,000 years. I soon learnt that Tasmania was once brimming with walking tracks, well-signposted with related historical information. Many of these tracks followed the original paths that the Aboriginals had put to use.

Circumambulatory knowing

Social anthropologist Tim Ingold (2004, p. 331–333) considers walking itself to be a form of circumambulatory knowing and, as such, a highly intelligent activity. Not only does he propose that through the continuous and never-ending process of walking, landscapes are woven into life but, also vice versa, that lives are woven into the landscapes. For me, walking is a multisensory experience during which the body perceives its surroundings through a diversity of senses. In this experience, seeing, hearing and smelling are combined with a moving body that adapts its movements to the surrounding landform. I enjoy this continuing movement that stimulates the entire body, especially when walking in an environment where the landform is not stable.

During longer walks, my mind travels freely, following sometimes surprising mental routes. I cherish this state of mind and do not usually interrupt the state by, for example, taking photographs or recording diary notes. However, while in Tasmania, and as the importance of walking gradually increased, my relationship with this documentation changed. First, I asked my partner to document certain moments and subjects during the walks that I found important. I also started to document some issues with my mobile phone camera.

During my stay in Hobart, walking became an elemental part of my everyday practice as I walked to my studio daily. In addition, during the weekends, I enjoyed the longer tracks. While walking, I imperceptibly moved to the mode of discovery, both in the sense of immaterial ideas and physical materials. The primary purpose of my walks was not to gather materials for my artistic practice; however, during most of the walks, I ended up collecting samples for my emerging collection of local soils (Figure 2b).

In Hobart, my practice proceeded initially by following two avenues, one being material experiments and the other drawing and painting. As these practices progressed, the two avenues finally encountered and melded into each other, resulting in a diversity of outcomes. I shall now discuss how the two avenues proceeded as a holistic, embodied making process in which making, thinking and walking practices served as catalysts for the entire creative process.

Experiments with soil

Soon after arriving in Hobart, I went for a short walk on the local beach. In addition to the working diary, I had with me some colours, brushes and one of the red stones I had recently found. I also carried with me some bark from a eucalyptus tree as these were the first 'treasures' I had picked up during my stay in Tasmania. At some stage of the walk, I sat down on the seashore and started to paint the forms and colours I found on the inside of the bark. The result was an abstract painting, and I decided to experiment by adding some colour that I was able to scratch from the red stone to the picture. With the water, this resulted in a bright ochre colour that seemed to adhere to the paper (Figure 3a).

I continued my painting experiments with the stones. The next steps were undertaken in my studio, which was situated in an abandoned ceramic workshop belonging to the Hobart College. It had the basic equipment to proceed with the experiments although most of the specific tools and machines had been removed when the workshop was closed. However, with a mortar, water and manual labour, I was able to transform the yellow stone and one of the red stones into a liquid form.

These liquids were used when I continued to paint with the earth-based materials I had collected. In the next step of the process, ordinary watercolours were abandoned, and all of the subsequently used colours were extracted from the earth samples collected (Figure 3b).

Following this, I painted figures with these colours. The result was surprisingly good, and I decided to follow this avenue in the painting experiments.

Figure 3: Painting experiments with (a) watercolours and stone and (b) stones. Maarit Mäkelä's working diary 21-22 January 2015. Photos: Peter Whyte.

At that time, I made my first test pieces in clay. In Hobart, my host was a ceramist, and she supplied me with recycled clay from a project she was currently working on. From this clay, which was white porcelain, I made test pieces that were then dipped in the three liquids (Figure 4). The test pieces were fired up to 1,260 °C. From these results, I could see that the black sand had smoothly melted on the top of the clay, and the colour varied from black to dark brown. The two other tests were different as the structure of the liquid was more granular. In addition, the colours had lost their intensity. Based on these results, I decided to continue my experiments in ceramics mainly with the black sand.

Figure 4: (a) Black sand, (b) red stone and (c) yellow sandstone ground and mixed with water, January 2015. Photos: Maarit Mäkelä.

I continued by adding paper to the same porcelain that I had already used in the test pieces. This enabled me to make very thin porcelain slabs that I could then use as canvases for my 'ceramic paintings'. Before I left Finland, I had visited the exhibition of Norwegian artist Edward Munch. I was deeply touched by his images, and I had taken some postcards with me that I had purchased from the exhibition. Two of these cards served as inspiration for my first painting experiments – both in paper and ceramics. In ceramics, the first images were painted with black sand and were inspired by his lithography *Lady with the Brooch* (1903).

Because of the success of the experiments, I continued by experimenting on the same topic in the form of double-sided 'ceramic paintings'. This resulted in pieces in which the final picture evolved on the top of the ceramics when light passed through the slab, making visible the white lines that had been painted on top of it. On the other side of the slab was the painting with black sand. The final image evolved on the top of the transparent slab with the aid of light as this combined these images into a single entity (Figure 5). At this stage, I felt that I was still too closely attached to Edward Munch's original figure and wanted to bestow my own touch on the image. I tried to modify the hair of the figure but could not get rid of the round forms that are typical of Munch's expression.

Figure 5: Double-sided painting on porcelain: (a) front painting with black sand and porcelain; (b) back painting with yellow stone; (c) front of the slab with proper lighting, February 2015. Photos: Peter Whyte.

Finding my personal visual expression

While working in the studio, I continued my walks in the local natural environment. I also walked daily to the studio, which was situated at the summit of Mount Nelson. I often followed a forest track to get there. The walk took one and a half hours, and during this time, I enjoyed the various views, sounds, smells and landforms that the track offered. One day, I had a longer walk to the nearby higher mountain. The track proceeded through forest towards low bushes, and thus, I was able to enjoy a full view of my surroundings. It was only during this walk that I finally understood the shape of the mountains (Figure 6).

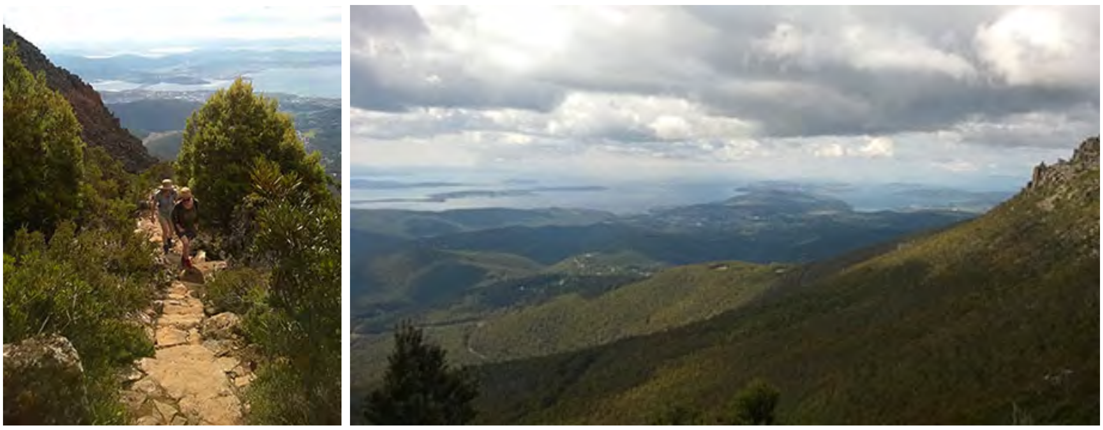


Figure 6: (a) Walking towards the summit of Mount Wellington; (b) scenery from Mount Wellington, February 2015. Photos: Pertti Mäkelä.

The following day, I walked along the familiar route to my studio through the forest in the rain. By combining the sound of the rain and the previous day's views, I suddenly understood that I was experiencing a different sensation of the forest. It was no longer only the immediate surrounding vegetal environment that I sensed, but instead, I became aware of the shape of the entire landscape, which consisted of countless rivulets through which the water was finding its way downward.

This multisensory experience corresponds to Tim Ingold's (2000; see also Pink, 2011, p. 266) proposal in terms of the relation between the eyes and ears: as the sensitive surfaces of the skin, these senses should not be understood as separate keyboards for the registration of sensation. Instead, 'they are to be understood as integral parts of the body that is continually on the move, actively exploring the environment in the practical pursuit of its life in the world' (Ingold, 2000, p. 261). Furthermore, he considers looking, listening and touching not as separate activities but, on the contrary, as different facets of the same activity – that of the whole organism in its environment. For me, the event in the forest was an important embodied experience during which I finally understood how the hair of the female figure should be painted. When I reached the studio, I painted the inner scenery on the paper (Figure 7).

Figure 7: Earth painting in the studio inspired by Edward Munch's lithography (figure on right), February 2015. Photo: Maarit Mäkelä.

This was not a unique endeavour as it is fairly common that when processing new ideas, artists and designers use drawing as a method for availing the process (e.g. Goel, 1995). For example, filmmaker Welby Ings (2014) refers to his own creative process in a discussion regarding his methodical use of drawing and interior dwelling to reach potentials beyond those available to the thinking prescribed by the written word. Within this construct – which he calls embodied drawing – the hand and pencil, as realising agents in the act of drawing, serve as tools transforming the image from the mind to the tangible world. As architect Juhani Pallasmaa (2009, p. 17) puts it: 'the pencil… is a bridge between the imagining mind and the image that appears on the sheet of paper'. In my own case, the act of drawing finally brought me to a satisfactory solution: the inspirational source, which is Munch's *Lady with the Brooch*, had led me to a new image that I could consider 'my own'. This was also the image that was later transformed onto the surface of two stones when I started my experiment with lithography.

The possibility of making lithography printing occurred because during my stay in Hobart, I was also collaborating with the University of Tasmania. The College of the Arts had an excellent printmaking studio, and this was the environment in which I conducted my first experiments with lithography. The image was made on top of a huge stone and then etched into it, and the colour was then applied to the top of the image and printed onto the paper. For the lithography, I applied the same theme as in the painting described above.

As the result was successful, I also wanted to try out whether my earth-based colours could be applied to lithography. As the time available to work in the printmaking studio was limited, I was encouraged to combine the lithography with my painting practice. This enabled me to proceed quickly. As a result, before printing the images with the lithography stone with the standard black colour, I painted the papers with my earth-based colours. I documented the following process in the working diary:

> Before printing, I painted the six sheets of paper with the earth colours I had made. The paintings were very wet and simple. While making them, I had in my mind the image that was going to be printed on top of these sheets … The image from the lithography stone and paintings settled down by itself where they belonged, and the outcome was much more that I had anticipated (Figure 8). (Working diary 4 March 2015)

The printmaking was undertaken at the end of my visit to Tasmania, and soon after that, I moved with these ideas, experiences and experiments further to New Zealand where the process continued.

Figure 8: *Ms Wellington*, lithography and earth painting, March 2015. Photo: Peter Whyte.

Conclusions

In Tasmania, my evolving creative process featured both serendipitous moments and intentional making. Cognitive scientist Ronald Finke (1996, p. 391) considers this interplay and proposes that the cognitive processes that underline creative thinking and imagination involve both conscious control and spontaneity. Thus, he believes that creativity is neither fully controlled and structured nor completely unplanned and unstructured. Accordingly, creative ideas, concepts and images can result either from the intentional working of the human mind or from its spontaneous, intuitive qualities. When considering the exploratory processes that occur outside an individual's awareness or consciousness, he or she can often sense meaningful directions of exploration in seeking to solve problems – even though he or she might not be aware of the actual reasons underlying these choices (Bowers, Regehr, Balthazard, & Parker, 1990). Shooler, Ohlsson and Srooks (1993, p. 166) maintain that it is important to not seek to verbalise or overregulate exploratory processes when searching for insights into how to solve problems.

During my creative process, I identified one problem that needed to be solved before I was able to attain the desired outcome: I had to find a new design for the hair of the female figure I was working on, which was inspired by Edward Munch's original image. Regardless of several conscious attempts to solve the problem with different media that already belonged to the sphere of my professional practice – that is by drawing, painting and ceramics – I remained unsatisfied with the result. Finally, I decided to place the problem aside as I knew this to be the way I usually found solutions to the most challenging problems I encountered. In this way, I relied on the natural emergence of a problem solution.

In my case, even if I decided not to allocate any effort to solving the problem, the unsolved problem became part of my everyday life – in a way, it dwelled constantly within me. Finke (1996, p. 390-391) clarifies the situation by noting that creative thinkers have a tendency to become deeply involved in a new idea, and they freely explore its creative implications. Therefore, they are good at seeing remote associations and connections, particularly those that cut across traditional conceptual boundaries. Even if I was not consciously aware, my embodied mind was constantly working with the problem.

In this case, walking emerged as an elemental part of my everyday practice: it gave direction to the entire creative process and was also the embodied practice per se through which the recently-emerged problem was solved. In the beginning, I began to familiarise myself with my new surroundings by walking. This led to the first 'discoveries' and sample gatherings in the form of the yellow sandstone. I simultaneously began to document the places where the gatherings occurred. Even when the materials found were further processed in the studio, the walks continued. Thus, walking and the local environment formed an important part of my creative practice, during which I not only gathered materials and inspiration for my art practice, but also proceeded with my related ideas and concepts. Finally, the solution to the problem that had occurred during the creative process was closely linked to the walking practice: I had identified the problem prior to a long walk a day before the solution occurred, and furthermore, the original insight that led to the solution appeared while walking in the rain.

It can be concluded that in my case, walking constructed an embodied practice that underpinned the creative process. In addition to walking, the process featured other embodied activities occurring mainly in the studio. These activities included painting, printmaking, ceramics and the related material experiments. This article has discussed the different phases of the creative process, revealing the interplay between the diversity of activities and how this gradually constructed and advanced the creative process. It has presented the author's personal creative process as a dialogue, featuring on one hand experiments and accidental discoveries and, on the other, careful planning and systematic making. The process proceeded as a dialogue between the action and the reflections of action that resulted in new works of art.

Acknowledgements
I am grateful to the ceramist Belinda Winkler for inviting me to share her studio on the premises of Hobart College. I am also thankful for the opportunity to proceed with my experiments in the printing studio at the University of Tasmania, College of the Arts, and especially to the Head of the studio, Jan Hogan, who kindly aided me with my experiments with lithography. Finally, I would like to praise my colleague Welby Ings from Auckland University of Technology for his insightful comments. This research is part of the Handling Mind research project funded by the Academy of Finland (project number 266125).

Maarit Mäkelä
Professor of Design
Aalto University School of Arts, Design and Architecture, Department of Design
Email address: maarit.makela@aalto.fi

References

Bennett, J. (2010). *Vibrant matter – A political ecology of things*. London: Duke University.

Brand, P. Z. (1999). Beauty matters. *The Journal of Aesthetics and Criticism, 57*(1), 1–10.

Bowers, K. S., Regehr, G., Balthazard, C., & Parker, K. (1990). Intuition in the context of discovery. *Cognitive Psychology, 22*, 72–110.

Eaton, M. M. (1997). Aesthetics: The mother of ethics? *The Journal of Aesthetics and Art Criticism 55*(4), 354–364.

Finke, R. A. (1996). Imagery, creativity, and emergent structure. *Consciousness and Cognition 5*, 381–393.

Goel, V. (1995). *Sketches of thought*. Cambridge, MA: Massachusetts Institute of Technology.

Groth, C., Mäkelä, M., & Seitamaa-Hakkarainen, P. (2015). Tactile augmentation: A multimethod for capturing experiential knowledge. *Craft Research, 6*(1), 59–83.

Hannula, M., Suoranta, J., & Vaden, T. (2005). *Artistic research – Theories, methods and practices*. Helsinki and Gothenburg: Academy of Fine Arts, Finland and University of Gothenburg, Sweden.

Ingold, T. (2000). *The perception of the environment*. London: Routledge.

Ingold, T. (2004). Culture on the ground. The world perceived through the feet. *Journal of Material Culture, 9*(3), 315–340.

Ings, W. (2014). Embodied drawing: A case study in narrative design. *Artifact, 3*(2), 2.1–2.10.

Koskinen, I., Zimmerman, J., Binder, T., Redström, J., & Wensveen, S. (2011). *Design research through practice: From the lab, field, and showroom*. London: Elsevier.

Mäkelä, M. (2007). Knowing through making: The role of the artefact in practice-led research. *Knowledge, Technology & Policy*, *20*(3), 157–163.

Mäkelä, M., & Latva-Somppi, R. (2011). Crafting narratives: Using historical context as a reflexive tool. *Craft Research, 2*, 37–60.

Mäkelä, M., & Nimkulrat, N. (*2011). Reflection and documentation in practice-led design research*. Paper presented at the 4th Nordic Design Research Conference NORDES, 29–31 May 2011, Helsinki, Finland. Retrieved from http://www.nordes.org

Mäkelä, M., & Löytönen, T. (2015). Enhancing material experimentation in design education. In R. Vande Zande, E. Bohemia, & I. Digranes (Eds.), *Proceedings of the 3rd International Conference for Design Education Researchers, Learn x Design Vol. 1*, (pp. 168–183). Helsinki: Aalto University.

Mäkelä, M., & O'Riley, T. (2012). Serendipity and Intentionality. In M. Mäkelä & T. O'Riley (Eds.), *The art of research II. Process, results and contribution* (pp. 6–32). Helsinki: Aalto University.

Nimkulrat, N. (2012). Hands on intellect: Integrating craft practice into design research. *International Journal of Design, 6*(3).

Pallasmaa, J. (2009). *The thinking hand. Existential and embodied wisdom in architecture*. Chichester: John Wiley & Sons.

Pedgley, O. (2007). Capturing and analyzing own design activity. *Design Studies, 28*(5), 463–483.

Pink, S. (2011). Multimodality, multisensority and ethnographic knowing: Social semiotics and the phenomenology of perception. *Qualitative Research, 11*(3), 261–276.

Schooler, J. W., Ohlsson, S., & Brooks, K. (1993). Thoughts beyond words: When language overshadows insight. *Journal of Experimental Psychology, 122*(2), 166–183.

Schön, D. (1991/1983). *The reflective practitioner. How professionals think in action*. New York: Basic Books.

Scrivener, S. (2002). Characterising creative production doctoral projects in art and design. *International Journal of Design Sciences and Technology, 10*(2), 25–44.

http://dx.doi.org/10.7577/formakademisk.1478

Pirita Seitamaa-Hakkarainen, Minna Huotilainen, Maarit Mäkelä, Camilla Groth and Kai Hakkarainen

How can neuroscience help understand design and craft activity? The promise of cognitive neuroscience in design studies

Abstract
Designing and making crafts is a complex, multifaceted process that requires sophisticated, professional thinking and competence, described as reflection in action and as an embodied process in which the hand, eye and mind collaborate. This article discusses these cognitive and embodied aspects central to designing and making crafts in light of cognitive neuroscience. Understanding the specific cognitive processes and forms of knowledge used in creative practices is essential. In this article, we propose that cognitive neuroscience provides valuable tools for analysing thinking and acting processes relevant to designing and making. We discuss the challenges and opportunities that the use of brain imaging methods, in particular, provides for understanding design activities, skills and cognition. Additionally, we present two neuroscientific experimental settings from our empirical studies in which the methods of cognitive neuroscience are applied to study and detect the interrelations between drawing, forming, skill learning and the functional activities of the brain and its subareas. We argue that cognitive neuroscience provides valuable instruments and methods which complement traditional design research.

Keywords: craft, design, making, cognitive neuroscience, brain imaging methods

Introduction

Designing is a goal-directed, iterative, creative activity that requires the sustained cultivation of sophisticated cognitive competencies (Simon, 1977; Ralph & Wand, 2009). Cognitive neuroscience, in turn, represents a multidisciplinary effort to analyse the neurobiological substrates underlying various cognitive processes using experimental methodologies from physiology, psychophysics, electrophysiology and functional neuroimaging. To what extent can cognitive neuroscience provide answers to scientific questions regarding the cognitive competencies related to designing and making? Designing and making are complex, multifaceted activities, but cognitive neuroscience studies typically investigate very simple and repeatable cognitive processes. Therefore, can reliable experimental settings that enable the detection of particular interrelations between design competencies and the functional activities of the brain and its subareas be created? How can design research benefit from the results of neuroscientific research? Until recently, design researchers lacked tools that enabled them to tackle the neural basis of designing (Goel & Grafman, 2000; Alexiou, Zamenopoulos, Johnson, & Gilber, 2009).

Although the body and mind traditionally have been studied separately, the recently emerged research field of embodied cognition integrates philosophy, psychology and neuroscience (Varela, Thompson, & Rosch, 1991; Lakoff & Johnson, 1999). Embodied cognition theory emphasises how cognition involves and builds on sensorimotor experiences through interactions with the environment (Koziol, Budding, & Chidekel, 2012). Research on embodied cognition has been conceptually elegant but included few empirical studies on design practice, in which embodiment plays a crucial role. However, it has been generally accepted that the mind is highly affected by the actions and experiences of the body, and vice versa (Hari & Kujala, 2009). Cognitive, sensory motor, emotional and social factors are all involved when creating a new item with the hands. Current research on brain systems is deepening understanding of the neural foundations of embodiment, skill learning and social interaction relevant to design and craft (for a review, see Hari & Kujala, 2009).

Designing and making crafts are understood to involve complex problem-solving processes in the mind–body which are fundamentally creative in nature and apply conceptual ideas to the design of material artefacts (Keller & Keller, 1999; Nilsson, 2013). As Nilsson (2013) has pointed out, the physical actions of making are essential in all creative practices in art, craft and design, both in relation to actual designing and to the uses of domain-specific knowledge. Emphasising the important role of materiality, some researchers have even proposed that making should be considered an academic discipline that encompasses a great variety of artefacts and human-made environments (Nilsson, 2013). Therefore, for us, art, craft and design stand as similar processes, and their enactments are both cognitive processes (ideation, problem solving) and embodied processes (experimenting, constructing and making).

Designing and craft making are fundamentally material centric, and engagement with and manipulation of physical materials are integral to these processes. Sketching, for instance, is generally considered the designer's most important thinking tool (Goel, 1995; Seitamaa-Hakkarainen & Hakkarainen, 2000). The selection of materials and tools for the specific design context often alters sketches produced during the process (Mäkelä & Nimkulrat, 2011; Kosonen & Mäkelä, 2012; Nilsson, 2013). Despite extensive study of visualisation, the role of material exploration and experimentations has not received as much attention (Ramduny-Ellis, Dix, & Evans, 2010).

The present study is part of the Handling Mind: Embodiment, Creativity and Design research project which integrates expertise in neuroscience, educational psychology and design research to develop and test neuroscientific methods for studying creative embodied processes and skill learning in the fields of art, craft and design. The goal of the present project is to generate and test hypotheses concerning design activity and the role and function of different brain areas in the design and craft processes. Design research, at present, shows two broad areas of deficiencies: 1) the investigation of the neuroscientific basis of design practice; and 2) empirical research on the embodied aspects of design. Advances in neuroscience indicate that naturalistic settings for studying design cognition are feasible. Therefore, we propose that cognitive neuroscience can be applied to study 1) design activity and associated cognitive processes; 2) the differences between design conditions and design fields; and 3) between-group differences related to the intensity and types of design training. We see cognitive neuroscience as an alternative tool for design studies that could complement more traditional design research.

To examine the challenges of conducting neuroscientific studies on design and crafts, we first review studies of design cognition focusing on the specific competencies of designing and cognition. We cover studies on design expertise related to analogical thinking (i.e. visual analogies) and visualisation, including spatial and mental rotation, and we address the relevance of distributed and embodied cognition to design. The second section provides a concise description of the cognitive neuroscience methods relevant to design research and highlights challenges to studying designing and skill learning. Finally, we describe two neuroscientific experimental settings from our empirical studies exploring these cognitive and embodied processes in designing and making. However, the detailed results of these studies are reported elsewhere.

Previous research on design cognition and embodiment

Studies on design expertise indicate that design thinking is a distinct mode of knowing (Cross, 2004, 2006; Lawson & Dorst, 2009). Design tasks entail complicated processes of searching for workable, aesthetic, functional solutions, and such tasks are commonly viewed as prototypical cases of complex, ill-defined problems (Goel & Pirolli, 1992; Goel, 1995) without unique or predetermined solutions (Simon, 1969, 1977; Akin, 1986). Design problems are also regarded as wicked in nature (Rittel & Weber, 1984). To manage the infinite possibilities, the designer must limit the design space by using external and internal constraints (Goel & Pirolli, 1992; Goel, 1995; Lawson, 2006). The design process involves successively reframing the design space and advances iteratively through cycles of ideation, testing and modification (Goel & Pirolli, 1922; Goel, 1995; Seitamaa-Hakkarainen & Hakkarainen, 2001). Only recently have researchers started to tackle problem-solving processes using neuroscientific research methods and to analyse differences in the pursuit of (ill-defined) design and well-defined problem-solving tasks (Goel & Grafman, 2000; Alexiou et al., 2009; Gilbert, Zamenopoulosb, Alexiou, & Johnson, 2010). Although research on design expertise emphasises designers' knowing, the intuitive aspects of the design process have not yet received much attention. According to Cross (2004), considerable work remains to adequately understand design expertise.

Research on expert/novice differences in problem-solving performance, starting in architectural design (Akin, 1986; Suwa & Tversky, 1997) and expanding to product design (Goel & Pirolli, 1992; Eisentraunt & Günther, 1997), played an important role in establishing the field of design research. Design studies have examined the knowledge, strategies and methods designers use to solve design problems (Akin, 1986; Goel & Pirolli, 1992). Most design studies have relied on empirical investigations tracing design processes by thinking-aloud protocols and have described design activity as movement through problem space (Akin, 1986; Goel, 1995; Seitamaa-Hakkarainen & Hakkarainen, 2001). Dorst and Cross (2001) proposed that the space of proposed solutions and the space of structuring problem co-evolve by moving design problems and solutions between these two spaces and by creating matching problem–solution pairs. Similarly, Seitamaa-Hakkarainen and Hakkarainen (2001) suggested that designers iteratively move between the composition (i.e. visual design) and construction design (technical) spaces.

Furthermore, analogical thinking and reasoning are important cognitive processes for creativity (Boden, 1992; Green, Kraemer, Fugelsang, Gray, & Dunbar, 2012) and designing (Ball & Christensen, 2009; Ozkan & Dogan, 2013). Analogical thinking is defined as a process of mapping and transferring information from one domain (source or analogy) to another domain based on similarities between the stimulus and target (Goldschmidt, 2001). Analogical reasoning moves from a known example to an abstraction and from an abstraction to a new idea to solve a problem (Casakin & Goldschmidt, 1999; Casakin, 2004; Ozkan & Dogan, 2013). Visual analogies are considered central strategies in solving design problems for both novices and expert designers (Casakin & Goldschmidt, 1999; Casakin, 2004). Visual displays act as stimuli and either expand the space of creative solutions (Goldschmidt & Smolkov, 2006; Goldschmidt & Sever, 2010) or constrain and recycle old ideas (Purcell & Gero, 1996). When abstract or unusual representations are used as possible source analogues, designers invoke more analogies and are better at analogizing (Perttula & Sipilä, 2007). To boost the use of analogies and to avoid cognitive fixation, many design studies have manipulated the given examples or the instructions for analogical thinking (for a review, see Ozkan & Dogan, 2013). Visual analogies improve design quality, and it is especially important that students learn to use analogies to improve their problem-solving processes (Casakin & Goldschmidt, 1999).

As discussed, a key aspect of design expertise and design cognition is the role of visualisation and visual representations (i.e. sketching and model making). According to Jacucci and Wagner (2007), the physical artefacts are representations of the work and emerge during the design process, while materiality is a vital aspect of design representations, indicating the conceptual and material aspects of design ideas. Research on sketching and drawing has attracted much interest among design researchers (Goel, 1995; McGown, Green, & Rodgers, 1998; Lawson, 2006; Perry & Sanderson, 1998; Seitamaa-Hakkarainen & Hakkarainen, 2000). Goel (1995) investigated the kinds of visual representations designers generate, especially the sketches they create to transform design tasks into the desired artefacts. Designers use various visual and concrete materials, three-dimensional (3D) models and abstract concepts (Al-Doy & Evans, 2011; Goldschmidt & Sever, 2010; Gonçalves, Cardoso, & Badke-Schaub, 2013) and reason and make decisions through the construction and manipulation of models of various sorts (Goel, 1995; Perry & Sanderson, 1998). Goel (1995) argued that designers produce and manipulate representations of artefacts rather than artefacts themselves and that designers are aware of the ways that various systems of representation affect their thought processes. Goel (1995; Perry & Sanderson, 1998) maintained that freehand sketches play an important role in the creative, explorative, open-ended phase of problem solving. Furthermore, designing requires the ability to handle spatial relations, orientation and mental rotation, that is, to learn to mentally manipulate the elements of complex spatial shapes. A designer needs these visual spatial abilities, for example, to perceive how a sketched drawing would look from behind or the side (Kavakli & Gero, 2001; Silvestri, Motro, Maurin, & Dresp-Langley, 2010). In addition, designers need to be able to imagine how materials might affect the design, for example, what kind of surface could be created with certain threads and weave structures.

As stated in the introduction, empirical research on embodied cognition has only recently emerged and has focused on the human body and associated bodily experiences. ‘Embodiment’ refers to the fact that a great deal of human thinking takes place at unconscious, implicit, non-linguistic levels (Lakoff & Johnson, 1999; Pfeifer & Bongard, 2006; Gibbs, 2005); therefore, we should not study the mind in isolation from the situated body. The mind and body are bound to a material world and to bodily experience (Varela et al., 1991; Lakoff & Johnson, 1999). However, empirical studies that combine the study of mind and body in relation to design and craft practice are extremely rare. Embodied cognition studies are aimed at understanding how the body and mind interact in the process of thinking, that is, how artisans relate their bodies, tools, materials and space in their work settings (Patel, 2008). Investigation of embodied processes is important as design activities are both physically and socially distributed (Hutchins, 1995). Physically distributed cognition refers to cognitive processes distributed through the material environment, concrete tools and physical artefacts that help solve more complicated tasks. Socially distributed cognition refers to cognitive processes distributed across the members of a social group, for example, among members of a design team. Both aspects of distributed cognition are crucial as designing frequently involves teamwork and relies on various material inspiration sources, representations and models. The emerging research field of social neuroscience emphasises the interactions among tools, the physical environment and the embodied activities in cognitive processes (Hari & Kujala, 2009). The skills of design and craft making are based on the extensive use of various embodied senses and tactual and sensor-motoric operations. As a multi-modal process, design activities involve tactile attention and processing, and studies indicate that designers’ senses never operate independently but are interrelated and embodied in one another (Spence & Gallace, 2007; Gallace, 2012). In learning a craft skill, the embodiment of tools and methods and the experiential knowledge of materials gained over time are crucial and lie at the heart of both design and craft practices. Practitioners of a skilled activity are attuned to working with a material, action or movement they have performed, encountered and handled countless times; without conscious effort, practitioners can imagine and predict the perceptual consequences of these actions. The human brain is a super-plastic entity that constantly reorganises itself according to the emerging and changing needs of activities (Hari & Kujala, 2009). When a particular activity is practiced intensively, the brain changes to facilitate performance of this activity, as in skill learning. Over two decades, the neural mechanisms involved in the perception or observation of motor activities have been intensely studied using a variety of neurophysiological and neuroimaging methods (for a review, see Rizzolatti & Craighero, 2004). Investigations have shown that the sensor motor areas of the brain are activated in response to using hand-related action verbs (Candidi, Leone-Fernandez, Barber, Carreiras, & Agliot, 2010)) and seeing other people working (Borghi & Cimatti, 2010) or hand-held tools (Witt, Kemmerer, Linkenauger, & Culham, 2010). Following another person's work activates the motor reflection of the mirror neuron system (Borghi & Cimatti, 2010). Therefore, analysing changes in neural activity associated with learning new craft skills appears to be important for expanding knowledge of design cognition.

To conclude, design cognition has been investigated extensively, but work on the neural basis of designing and making is lacking. Cognitive neuroscience does not tell us what or how designers think but can be used to analyse their activities in specific situations and to trace brain activity associated with their problem solving. Next, we briefly describe neuroscience methodologies and highlight challenges in studying designing and skill learning.

Brain research methodologies and their relation to design research

Despite rapid advances in neuroscientific research, the challenge is to develop experimental settings that allow examination of the interrelations between brain activity and design cognition, especially in more naturalistic settings. All neuroscience methods, however, have limitations that affect the feasibility of the types of investigation and research questions posed. In the following section, we introduce some neuroscientific research methodologies and explain how they can be applied to study design cognition. Then, we illustrate how we created neuroscientific research settings to investigate skill learning and to study drawing and forming.

First, functional magnetic resonance imaging (fMRI) is a neuroscientific instrument that can provide a complete picture of the brain activity involved in solving complex design tasks. In fMRI, the blood-oxygenation-level-dependent (BOLD) signal is used to detect any changes in brain areas caused by fluctuations in oxygen use during the task. This method can produce a full image of brain areas and their oxygen use. Traditional fMRI experiments shed light on the following types of questions: 1) Which brain areas are activated in task A compared to task B? 2) Do individuals in group X and group Y have different brain areas activated by task A and task B? Such questions are of great importance in comparing design professionals and novices and in assessing different design tasks and their neural correlates.

Many design researchers argue that it is important to distinguish between ordinary problem-solving tasks and design tasks (Goel & Pirolli, 1992; Cross, 2004). The prefrontal cortex serves as the neural basis of higher-order cognitive functions and is involved in complex planning, creative thinking and problem solving (Goel & Grafman, 2000; Speed, 2010). To examine the neural basis of planning, problem solving and creative thinking in design, Alexiou et al. (2009) used fMRI to analyse differences between ill-defined design and well-defined problem-solving tasks. Alexiou et al. (2009) revealed different patterns of brain activation in the study phase (learning a task) and the performance phase (moving objects). In particular, the right dorsolateral prefrontal cortex showed greater activity during design than problem-solving tasks (Gilbert et al., 2010). Overall, design tasks required a more extensive network of brain areas than well-defined tasks. Different parts of the premotor cortex were activated when shifting from the learning phase to moving objects (Alexiou et al. 2009; Gilbert et al., 2010). As well, the motor and premotor areas of the brain were activated not only when performing but also when observing particular movements (Alexiou et al. 2009). According to Alexiou et al., (2009), it appears important to better understand the role of doing in designing and its relation to visual, spatial and verbal reasoning.

However, in fMRI experiments, participants usually cannot move and are restricted to a recumbent position in the cylindrical tube of an fMRI scanner. A head coil is placed on the top of a participant's head, and a mirror is attached to the head coil. In an experiment, the stimulus is projected onto a screen outside the scanner but within participant's field of vision (Alexiou et al., 2009; see also Gilbert et al., 2010). Participants use a mouse to click and drag objects displayed on the screen. A challenge in fMRI studies is to design valid experiments that can be performed without extensive movements. Such studies must be sufficiently complex to qualify as prototypical design tasks but simple enough to be solved within the time constraints imposed by the brain imaging methodology.

Some neuroscientific analogy studies using fMRI have confirmed that the activation of various areas in the prefrontal cortex can be seen as a key component in a larger network for making analogies (Bunge, Wendelken, Badre, & Wagner, 2005; Luo et al., 2003; Speed, 2010). Although it is not clear exactly how this network achieves analogical reasoning (Speed, 2010), fMRI can be employed to study the neural basis of visual analogical thinking, for example, by comparing experts and novices or participants from different design field. Earlier design research (Casakin, 2004; Ozkan & Dogan, 2013) provided excellent examples and a baseline for planning an experimental setting to study visual analogies: the type of design tasks, visual analogy categories and visual displays (i.e. visual stimuli). When applying this setting to an fMRI study, the visual display could be projected onto the computer screen, and experts and novices could identify and rate images by clicking a mouse or move objects by dragging them. Such an investigation is suitable for assessing the impact of the expertise level or the design field on the preferred distance of source analogues (see Casakin, 2004; Ozkan & Dogan 2013). First-year students without previous design experience can be useful to determine a baseline. Following the set-up used by Casakin (2004) and Ozkan and Dogan (2013), the fMRI experiment could consist of several carefully planned sub-tasks. The visual stimulus could be within-domain images from the domain studied and between-domain images from remote domains. Task participants could evaluate the usefulness of each provided visual stimuli as a source domain for designing a field-specific object (e.g. a lamp) or choosing the analogy category (e.g. architecture, artefacts, nature, lamps) that best serves as an analogical source domain for designing particular objects. The fMRI could be used to compare experts' and novices' different preferences of within- and between-domain visual stimulus. However, a main limitation of using fMRI in visual reasoning is that studying actual design process (cf. Casakin, 2004) is impossible as conducting brain imaging during the act of drawing is impeded by the necessary restriction of movement.

The fMRI setting can also be used to examine skills of two-dimensional (2D) and 3D spatial reasoning and mental rotation. Most designers are trained as visualizers and have acquired specific visual skills and competencies (Goodwin, 1994). As stated, these skills require the ability to handle spatial relations, orientation and mental rotation, that is, to learn to mentally manipulate the elements of complex spatial shapes. For example, in garment design, a flat-pattern design is central to form giving, and the 3D form is developed in two dimensions (Salo-Mattila, 2014). Shepard and Metzler (1971) introduced the concept of mental rotation. In their experiment, participants were presented with a pair of perspective line drawings of chiral shapes (i.e. asymmetrical 3D cubes). Each pair was rotated from its original position by a certain amount, and participants were shown the mirror image of the 3D cubes. Participants were asked to indicate as quickly as possible by pressing a button whether the two objects depicted were identical or mirror images. Recently, mental rotation has been investigated using several neuroscientific techniques, including fMRI (e.g. Cohen et al., 1996; Jordan, Heinze, Lutz, Kanowski, & Jäncke, 2001; Vingerhoets, de Lange, Vandemaele, Deblaere, & Achten, 2002).

Cohen et al. (1996) repeated Shepard and Metzler's (1971) classic study using fMRI to observe local changes in blood flow in the brain during mental rotation. In the study, the comparison condition was identical to that in Shepard and Metzler's (1971) study, except that both members of each pair appeared at the same orientation, and mental rotation was not needed. The study revealed that mental rotation engages cortical areas involved in tracking moving objects and encoding spatial relations (Cohen et al., 1996). Given the extensive research on the mental rotation of 3D objects, Cohen's et al. study might provide a model for an experimental setting to study expert/novice and design-field-related differences in 2D and 3D spatial-reasoning skills and mental rotation. In design contexts, mental rotation can be studied by comparing the previously described classic settings with various visual objects (e.g. different sorts of stimuli pairs, pictures of hands and tools) and by comparing experts, novices and laypeople. Novice and expert designers are likely to respond differently to diverse stimuli modalities, while differences between design professions (e.g. architecture, industrial design, graphic design) might be related to working with 2D- or 3D representations.

Another method called optical imaging can provide further possibilities for studying visual reasoning outside the laboratory. Optical imaging, or near infrared spectroscopy (NIRS), utilizes changes in the absorption and scattering properties of light as it travels in brain tissue. When brain tissue is active, more oxygenated blood travels to the area, and in event-related optical signals (EROS), brain activity affects chemicals and liquids in the brain, prompting changes in the properties of light absorption and scattering (Gratton et al., 2001). Optical imaging thus might allow combining measurements of BOLD-type signals and event-related neuronal measures (Gratton et al., 2001). In addition, optical imaging is portable and does not require a laboratory facility, so it can be used in natural working environments. Therefore, optical imaging is a promising area for advancing design-related brain studies. For example, 2D and 3D representations and spatial reasoning skills can be seen as the core of professional training in many design fields. Designers manipulate various 2D (e.g. drawings, garment patterns) and 3D representations (e.g. physical mock-ups, clothing) and mathematical relations, such as proportions (Ho, Eastman, & Catrambon, 2006). These authentic activities could be studied using optical imaging in natural working environments.

Electroencephalography (EEG) is the oldest brain research method and provides millisecond-scale temporal accuracy. EEG and event-related potentials (ERP) are fast methods not limited to laboratory settings. EEG signals are the result of the synchronous activity of neuronal assemblies which can be recorded at the surface of the scalp. EEG might be able to trace expert/novice differences in design-related brain activity (Alexiou et al., 2009), and the availability of portable, lightweight EEG instruments permits performing such investigations in the natural working environments of designers. ERPs are averaged fragments of EEG which indicate brain activity that is temporally related to events, such as the presentation of an image or the beginning of a sound, task or attempt. Visual, somatosensory and auditory components (peaks) of ERPs have been observed, and some features of their relationships to the cognitive functions of perception, memory and attention have been identified. As stated, previous research has revealed activation of the brain's sensor motor areas in response to the stimuli of seeing other people working (Borghi & Cimatti, 2010) or hand-held tools (Witt et al., 2010). Moreover, recently published neuroscientific studies analysing the effects of drawing on alpha activity (Belkofer, Van Hecke, & Konopka, 2014) and comparing brain activity during drawing and sculpting (Kruk, Aravich, Deaver, & deBeus, 2014) have used EEG to examine the brain wave frequency patterns of participants engaging in art-making conditions. Thus, the long tradition of ERP research provides a good basis for application to design research. Pursuit of design tasks, however, might pose challenges for the ERP method due to the different time courses of the consecutive sub-tasks in the process. A clear disadvantage of EEG measurements compared to fMRI is the difficulty in identifying the brain areas, especially deeper regions, that contribute to the elicitation of responses. Thus, the strengths and weaknesses of the methods complement each other. In the next section, we explicate in more detail our neuroscientific experiments on 1) skill learning; and 2) drawing and forming using EEG instruments.

Measuring skill learning, drawing and forming with EEG

Our first neuroscience laboratory experiments examined the neural foundations of novices' process of acquiring new skills. We conducted an EEG study on how specific craft skills are learned. The participants were first-year university textile student-teachers and adults from Martta organization who voluntarily participated in the study. None had previous knowledge of the techniques learnt during the experiment. Modelling, coaching and scaffolding are traditional ways of learning specific craft skills during apprenticeships. Observation, guided practice (Collins, 2006), careful imitation and deliberate practice (Ericsson et al., 1993) play crucial roles in this process. Learning a new craft skill should activate the sensory motor areas of the brain when the participant receives certain stimulus (i.e. photos of hand positions during the craft technique). Thus, our laboratory experiment examined the neural foundations of novices' process of acquiring new skills and was aimed at answering the following research questions: 1) What brain activations are observed when participants look at instructions for craft techniques which they know and do not know? 2) How does skill learning change these activation patterns? 3) Does skill learning change the timing of the brain activity? In particular, we were interested in the role of motoric training in the skill learning process and its neural basis, as well as the brain organisation and large-scale memory systems of self-paced, intensive skill learning.

Figure 1 shows the research setting of the skill learning experiment. EEG measurements were performed before and after learning a specific textile craft skill. Electrodes were placed at various locations on participants' scalps to measure the voltage of synchronous electrical activity of neurons at those locations. During measurements, participants' brain responses were recorded using a NeurOne EEG-instrument (Mega Electronics Ltd, Finland) with 32 EEG and EOG channels. The EEG procedure enables illustrating brain activity during real-time viewing and action and is non-invasive and much less cumbersome than other brain imaging systems.

Figure 1. EEG equipment used in research on skill learning.

The 15 novice participants were shown 312 instructional photographs (i.e. working instructions) for three textile techniques. Most participants were familiar with one technique (crocheting), whereas the two other textile techniques (filet lacing and frivolite, or tatting) were previously unknown to or barely known by participants. Figure 2 shows examples of the photographs of the hand positions in the working instruction. These photographs were shown in a random order first before participants learnt a specific skill (textile technique) and then again after the technique was learnt and practiced. These participants were considered novices as, although they knew some textile techniques, they did not know the specific techniques used in this study (filet lace, frivolite). Brain responses to the photographs were averaged together across the sessions and across the participants.

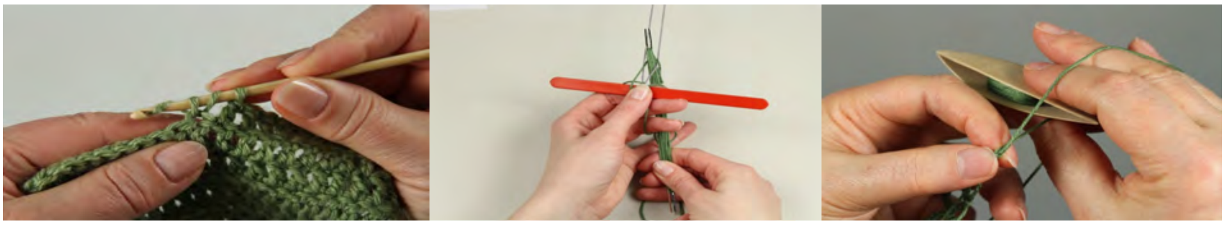


Figure 2. Photos of hand positions for textile techniques (from left to right): 1) crocheting; 2) filet lace; and 3) frivolite.

During a four-week period, the two groups of participants learnt one of two specific craft techniques: frivolite (tatting) or filet lace. After an expert taught these techniques in one session, participants independently practiced the skill and kept diaries of their own learning during the practice period. The EEG recording was then repeated, and the results from the first and second sessions were compared. After the experiment, the participants were interviewed. This kind of research setting is completely new in the design field, so we attempted to construct a rigorous, reliable research design. Figure 3 presents our brain research design to measure brain responses to images related to the three techniques.

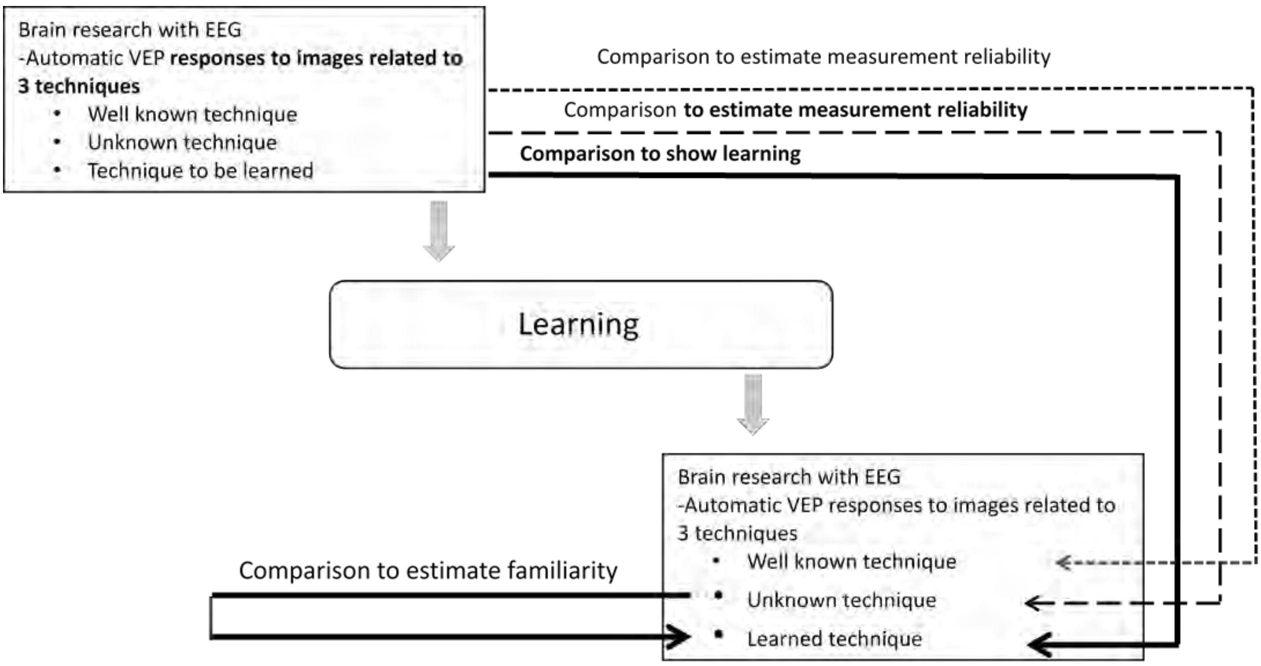


Figure 3. Skill learning research design.

We expected that, in addition to the visual processing, the motor or somatosensory areas would be activated while looking at the photographs. After learning the skill, this involvement likely would change, and some brain responses likely would become faster. Thus, by comparing participants' first and second recordings of the well-known technique (crocheting), we estimated the reliability across these two measurements. Similarly, comparing participants' first and second recordings of the unknown techniques provided another estimate of measurement reliability. Comparing the technique to be learnt in the first recording to the technique learnt in the second recording revealed the learning from the brain activity.

We report details of our results elsewhere but can conclude that we appeared to be able to capture the activated somatosensory areas and that the results indicated no differences in the known and unknown technique. These results confirmed that we measured the right phenomena. However, there were larger, positive changes in the brain responses to learned skill photos, indicating that participants more quickly recognised the photographs of hand positions related to the learned skill.

We conducted another neuroscientific experiment in which neurone EEG instruments and Faros (Mega) cardiac recordings were used to test hypotheses about the neural and physiological activity associated with producing visual representations (i.e. replicating drawings versus creating new designs) and material representations (i.e. replicating models versus creating new designs) (Leinikka, Huotilainen, Seitamaa-Hakkarainen, Groth, Rankanen, & Mäkelä, 2016). Only recently have some published neuroscientific studies analysed the effects of drawing on alpha activity (Belkofer et al., 2014) and compared brain activity during drawing and sculpting (Kruk et al., 2014). These studies (Belkofer et al., 2014; Kruk et al., 2014) used EEG to examine the brainwave frequency patterns of participants engaging in art making. In general, non-event-locked physiological and brain activity takes place in specific patterns related to cognitive processes and in responses to any stimuli present in the environment (Kruk et al., 2014). Theta waves were shown to be related to imaginative states and creative processes, alpha waves were detected in relaxed and normal conscious awareness, and beta waves were expressed during active thought and alert states (Kruk et al., 2014). Finally, gamma waves were correlated with cross-modal stimulus integration, synthesis and information-rich processing (Luck, 2005).

A previous EEG study by Kruk et al. (2014) showed that, compared to general movement, both clay sculpting and drawing increased gamma power in the right medial parietal lobe. In addition, clay sculpting decreased right medial frontal gamma power and elevated theta power. Also, Belkofer et al. (2014) indicated that alpha rhythm might play an important role in drawing. The results of both studies were discussed in the context of art therapy.

Thirty participants, both students and professionals, representing expertise in various design fields, participated in our study. Participants were regarded as experts in drawing from Aalto University. The question investigated was whether the brain responses to working with visual (drawing) or material (moulding clay) representations differed in the tasks of 1) copying; 2) creating novel designs; and 3) freely improvising. In the clay-moulding task, participants worked with clay material; otherwise, the tasks were similar. To measure participants' physiological responses to the copying, designing and free-improvisation tasks, we recorded their heart-rate variability (HRV) through the Faros and Aktigraph (i.e. pulse and movements) measurement.

In the drawing experiment, participants individually constructed three drawings: 1) a copy of a line drawing of a cup (copying task); 2) a creative design of a cup (design task); and 3) a creative drawing of a self-chosen topic (free improvisation task). The experimental setting consisted of 2 time blocks: a fast block and a slow block. Before drawing (or moulding clay), participants looked at the picture of the cup for 5 seconds and then a fixation cross for 10 seconds. This fixation cross was important for physiological measurements. In the fast block, the time for drawing or moulding was restricted to 45 seconds, but in the slow block, the time was extended to 3 minutes. Each block and each task was randomly assigned to participants and repeated 5 times. The same setting was conducted for 8 selected participants using a NeurOne EEG-instrument with 32 EEG channels that recorded participants' brain activity and tracked their HRV, which were all recorded in time synchrony with the tasks. In these experiments, we expected that the brain responses during the 10-second period of preparation to perform the tasks would differ according to the task. We assumed that the visual areas would be mainly activated in task 1 (visible through the suppression of the alpha rhythm), while motor areas would be more active in tasks 2 and 3 (visible through the suppression of the mu-rhythm). As well, the activity in the frontal areas of the brain would differ between tasks 2 and 3 due to the level of creativity required (see also Belkofer et al., 2014; Kruk et al., 2014). The experiments contribute to a novel understanding of the creative process compared to the copying task. Already in the physiological recordings, we observed a physiological response to the materials (drawing vs. forming clay) in the HRV parameters (Leinikka et.al, 2016).

Conclusion

Academic research on art, craft and design involves the analysis of design activities, creative processes and their consequences for the human mind and wellbeing. Learning through designing and constructing craft products appears to play an essential role in human development and facilitates the development of cognitive, spatial, motor, social and aesthetic skills. In addition, the artistic processes integral to crafts are central to emotional expression and regulation of human well-being and flourishing. Thus, success in the art, crafts or design fields depends on mastery of the entire design and craft process, from the generation of ideas to the learning of techniques and the production of visual and material artefacts. Participants must manage the procedures of planning, making and integrating mental representations into the surrounding material, physical and societal conditions, as well as reflecting possibilities and testing the boundaries of self-fulfilment.

In this article, we have reviewed research on the design cognition and competencies that constitute design expertise, and we have highlighted the importance of embodiment for skill learning. We also introduced our neuroscientific experiments to capture the neuroscientific basis of skill learning and to work with materials, that is, drawing and forming. The present examination reveals that the methods of neuroscience might open many interesting lines of design research. A limitation of traditional cognitive research on design is an overemphasis on deliberate the within-mind processing of conceptual or visual information. However, practitioners' accounts of their design experiences have tended to be subjective descriptions of their practices that are difficult to systematise to allow the accumulation of research design knowledge.

The rapidly advancing methods of neuroscience provide new possibilities to experimentally trace the interrelations between brain activity and design cognition. The brain changes and forms according to different physical and mental activities. Further, an exciting, new trend in neuroscience is to compare the brain structures of various professionals. It is an inspiring challenge to design an experimental setting to study the functional and structural changes of the brain related to learning and practicing special design skills.

However, all neuroscience methods have their limitations for addressing the research questions. Most neuroscientific equipment cannot be removed from the laboratory, and measuring brain activity requires expertise in neuroscience. As stated, neuroscience studies typically investigate very simple, repeatable cognitive processes, whereas designing and making crafts are complicated, multi-faceted activities. Therefore, it is difficult to create reliable, valid experimental settings in which to identify and determine the specific interrelations between design cognition and brain activity. Although we recognise the limitations of the cognitive neuroscience methods, we suggest that it can be seen as an alternative tool for design studies, appropriately accompanied by more traditional design research.

In Table 1, we summarise the pros and cons of the neuroscience methods in the context of design studies. Moving from the right to left column are the method name, parameters measured, temporal resolution (accuracy in time) and spatial resolution (how well the active brain areas are located). The strengths and weaknesses of the methods are described. As indicated in Table 1, some methods (fMRI) in the sequence of design activities are difficult to study, whereas EEG offers a long tradition of well-controlled experiments that can be applied in design studies. NIRS is a portable instrument but is not yet widely used in cognitive studies.

Table *1. Pros and cons of neuroscientific methods for design studies.*

Neuroscientific method	**Parameters measured with this method**	**Temporal resolution (accuracy in time)**	**Spatial resolution (accuracy of locating active brain areas)**	**Pros for design studies**	**Cons for design studies**
fMRI (functional magnetic resonance imaging)	BOLD-signal (blood-oxygenation-level-dependent signal), changes in blood flow after increased neuronal activity	Block design studies: several seconds to minutes Event-related studies: hundreds of milliseconds	From several millimeters to sub-millimeter accuracy	Some fMRI study protocols are quite well suited for design studies	Equipment cannot be removed from the laboratory; sequence of activities is difficult to study
EEG (electroencephalo-graphy)	Electric potentials from scalp, directly resulting from neuronal activity	Less than a millisecond	Problematic due to distortion of electric potentials, less than 1 cm in good conditions	Portable instruments, natural environments, some EEG study protocols are quite well suited for design studies, measurements of several hours are practically possible	Location of brain activity is difficult to determine
MEG (magnetoencephalo-graphy)	Magnetic fields outside the head, directly resulting from neuronal activity	Less than a millisecond	Less problematic than EEG, in good conditions clearly less than 1 cm	Some MEG study protocols are quite well suited for design studies, long tradition of well-controlled experiments stemming from EEG, optimal time-space-resolution	Equipment cannot be removed from the laboratory; location of brain activity is quite difficult to determine
MRI (magnetic resonance imaging)	Structures of the brain (structural MRI), neural tracts (DTI, diffusion tensor imaging)	No accuracy in time	Less than 1 mm	Good for studies comparing groups of people	Equipment cannot be removed from the laboratory
PET (positron emission tomography)	Structural image of concentration of metabolically active tracer, usually oxygen	Contrast of two conditions: no accuracy in time	Less than 1 cm	Good for comparing groups of people or natural tasks	Radioactive tracer is injected into participants; equipment cannot be removed from the laboratory
NIRS (near-infra-red spectroscopy)	Diffusion and absorption of near-infra-red light in tissues, depending on hemodynamic and electromagnetic changes in brain tissue	hemodynamic NIRS: hundreds of milliseconds, electromagnetic NIRS: millisecond (according to some researchers)	Theoretically less than 1 cm	Portable instruments, natural environments, some NIRS study protocols are quite well suited for design studies, measurements of several hours are practically possible	Difficulties in determining the location of brain activity, not many groups yet using NIRS for cognitive studies

To conclude, research on distributed and embodied cognition has assisted in expanding design research beyond the focus on mind to consider bodily, materially and socially distributed processes critical in design. As demonstrated in the present article, neuroscience provides instruments and methods which can be applied to study design competencies. In this article, we have tentatively sketched some directions for neuroscientific research to study design cognition, and we have described our own neuroscientific experiments. However, much future research is needed to deeply understand designing and making crafts from the neuroscience perspective.

Acknowledgement
The research was funded by the Handling-Mind Project (Academy of Finland, projects 265922 & 266125).

Pirita Seitamaa-Hakkarainen
Professor
University of Helsinki, Faculty of Behavioural Sciences
Email address: pirita.seitamaa-hakkarainen@helsinki.fi

Minna Huotilainen
Professor
University of Turku
Email address: minna.huotilainen@utu.fi

Maarit Mäkelä
Professor of Design
Aalto University School of Arts, Design and Architecture, Department of Design
Email address: maarit.makela@aalto.fi

Camilla Groth
Doctoral Candidate
Aalto University, School of Arts, Design and Architecture, Department of Design.
Email address: camilla.groth@aalto.fi

Kai Hakkarainen
Professor
University of Helsinki, Faculty of Behavioural Sciences
Email address: kai.hakkarainen@helsinki.fi

References

Akin, Ö. (1986). *Psychology of architectural design*. London, UK: Pion.

Al-Doy, N., & Evans, M. (2011). A review of digital industrial and product design methods in UK higher education. *The Design Journal, 14*(3), 343–368.

Alexiou, K., Zamenopoulos, T., Johnson, J., & Gilbert, S. (2009). Exploring the neurological basis of design cognition using brain imaging. *Design Studies 30(6)*, 623–647.

Ball, L. J., & Christensen, B. T. (2009). Analogical reasoning and mental simulation in design: Two strategies linked to uncertainty resolution. *Design Studies*, 30(2), 169-186.

Belkofer, C, Van Hecke, A., &. Konopka, L. (2014). Effects of drawing on alpha activity: A quantitative EEG study with implications for art therapy. *Art Therapy: Journal of the American Art Therapy Association*, *31*(2), 61–68.

Boden, M. (1992). *The creative mind*. London, UK: Sphere Books.

Borghi, M., & Cimatti, F. (2010). Embodied cognition and beyond. *Neuropsychologia*, *48(3)*, 763–773.

Bunge, S., Wendelken, C., Badre, D., & Wagner, A. (2005). Analogical reasoning and prefrontal cortex: Evidence for separable retrieval and integration mechanisms. *Cereb Cortex*, *15(3)*, 239–249.

Candidi, M., Leone-Fernandez, B., Barber, H., Carreiras, M., & Agliot, S. (2010) Hands on the future: Facilitation of cortico-spinal hand-representation when reading the future tense of hand-related action verbs. *European Journal of Neuroscience*, *32(4)*, 677–683.

Casakin, H. (2004). Visual analogy as a cognitive strategy in the design process: expert versus novice performance. *Journal of Design Research*, *4*(2),1-18.

Casakin, H., & Goldschmidt, G. (1999). Expertise and the use of visual analogy. *Design Studies*, *20*(2), 153–175.

Cohen, M., Kosslyn, S., Breiter, H., DiGirolamo, G., Thompson, W., Anderson, A., Bookheimer, S., Rosen B., & Belliveau, J. (1996). Changes in cortical activity during mental rotation. A mapping study using functional MRI, *Brain*, *119 (1)*, 89–100.

Collins, A. (2006). Cognitive apprenticeship. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (pp. 47–60). Cambridge, UK: Cambridge University Press.

Cross, N. (2004). Expertise in design: An overview. *Design Studies, 25*(5), 427–441.

Cross, N. (2006). *Designerly ways of knowing*. London, UK: Birkhäuser.

Dorst, K., & Cross, N. (2001). Creativity in the design process. *Design Studies*, 22(5), 425–437.

Eisentraunt, R., & Günther, J. (1997). Individual styles of problem solving and their relation to representations in the design process. *Design Studies*, 18(4), 369–384.

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review 100(3)*, 363–406.

Gallace, A. (2012) Living with touch. *The Psychologist: The British Psychological Society*, *25*, 896–899. Retrieved from http://www.thepsychologist.org.uk/archive/archive_home.cfm?volumeID=25&editionID=220&ArticleID=2186

Gibbs, R. (2007). *Embodiment and cognitive science*. New York, NY: Cambridge University Press.

Gilbert, S., Zamenopoulosb T., Alexiou, K., & Johnson J. (2010). Involvement of right dorsolateral prefrontal cortex in ill-structured design cognition: An fMRI study. *Brain Researcher*, *1312*, 79–88.

Green, A., Kraemer, D., Fugelsang, J., Gray, J., & Dunbar, K. (2012). Neural correlates of creativity in analogical reasoning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*(2), 264–272.

Goel, V., & Pirolli, P. (1992). The structure of design problem space. *Cognitive Science*, *16*(3), 395–429.

Goel, V. (1995). *Sketches of thought*. Cambridge, MA: MIT Press.

Goel, V., & Grafman, J. (2000). Role of the right prefrontal cortex in ill-structured planning. *Cognitive Neuropsychology*, *17*(5), 415–436.

Goldschmidt, G. (2001). Visual analogy. In C. Eastman, M. McCracken, & W. Newstetter, W. (Eds.). *Design, Knowing and Learning: Cognition in Design Education* (pp. 199–219). Oxford, UK: Elsevier.

Goldschmidt, G., & Smolkov, M. (2006). Variances in the impact of visual stimuli on design problem solving performance. *Design Studies*, *27*(5), 549–569.

Goldschmidt, G., & Sever, A. (2010). Inspiring design ideas with texts. *Design Studies, 32*(2), 139–155.

Gonçalves, M., Cardoso, C., & Badke-Schaub, P. (2014).What inspires designers? *Design Studies*, *35*(1), 29–53.

Goodwin, C. (1994). Professional vision. *American Anthropologist, 96*(3), 606–633.

Gratton, G., Goodman-Wood, M. R., & Fabiani, M. (2001). Comparison of neuronal and hemodynamic measures of the brain response to visual stimulation: An optical imaging study. *Human Brain Mapping 13(1)*, 13–25.

Hari, R., & Kujala M. M. (2009). Brain basis of human social interaction. *Physiological Reviews*, *89(2)*, 453–479.

Ho, C-H, Eastman, C., & Catrambon, R. (2006). An investigation of 2D and 3D spatial and mathematical abilities. *Design Studies*, *27*(4), 505–524.

Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.

Jacucci, G., & Wagner, I. (2007). Performative roles of materiality for collective creativity. In *Proceedings of the 6th ACM SIGCHI conference on Creativity, & Cognition* (pp. 73–82). New York, NY: Association for Computing Machinery.

Jordan K., Heinze, H-J., Lutz, K., Kanowski, M., & Jäncke, L. (2001). Cortical activations during the mental rotation of different visual objects. *NeuroImage, 13*(1), 143–152.

Kavakli, M., & Gero, J. (2001). Sketching as mental imagery processing. *Design Studies*, *22*(4), 347–364.

Keller, C. M., & Keller, J. D. (1999). Imagery in cultural tradition and innovation. *Mind, Culture, and Activity*, *6*(1), 3–32.

Kosonen, K., & Mäkelä, M. (2012). Designing platform for exploring and reflecting on creative process. *Procedia—Social and Behavioral Sciences*, *45*, 227–238.

Koziol L., Budding D., & Chidekel, D. (2012). From movement to thought: Executive function, embodied cognition, and the cerebellum. *Cerebellum 11(2)*, 505–525.

Kruk, K., Aravich, P., Deaver, S., & deBeus, R. (2014) Comparison of brain activity during drawing and clay sculpting: A preliminary qEEG study. *Art Therapy: Journal of the American Art Therapy Association*, *31*(2), 52–60.

Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh*. New York, NY: Basic Books.

Lawson, B., & Dorst, K. (2009). *Design expertise*. Oxford, UK: Architectural Press.

Lawson, B. (2006). *How designers think: The design process demystified* (4th ed.). Oxford, UK: Architectural Press.

Leinikka, M., Huotilainen, M., Seitamaa-Hakkarainen, P., Groth, C., Rankanen, M., & Mäkelä, M. (2016). *Physiological measurements of drawing and forming activities*. Design Research Society conference, 27–30 June 2016, Brighton, UK.

Luck, S.J. (2005). *An introduction to the event-related potential technique*. Cambridge, MA: MIT Press.

Luo, Q., Perry, C., Peng, D., Jin, Z., Xu, D., Ding, G., & Xu, S. (2003). The neural substrate of analogical reasoning: An fMRI study. *Cognitive Brain Research. 17(3)*, 527–534.

McGown, A., Green, G., & Rodgers, P. (1998). Visible ideas: Information patterns of conceptual sketch activity. *Design Studies*, *19*(4), 431– 453.

Mäkelä, M., & Nimkulrat N. (2011). Reflection and documentation in practice-led design research. In I Koskinen, T. Härkäsalmi, R. Mazé, B. Matthews, & J.-J. Lee (Eds.), *Making Design Matter, Proceedings of the 4th Nordic Design Research Conference 29–31 May 2011* (pp. 120–128).

Nilsson, F. (2013). Knowledge in the making. On production and communication of knowledge in the material practices of architecture. *FORMakademisk*, *6*(2), 1–13

Ozkan, O., & Dogan, F. (2013). Cognitive strategies of analogical reasoning in design. *Design Studies, 34*(1), 161–192.

Patel, K. (2008). *Thinkers in the kitchen*. Ann Arbor, MI: UMI Dissertation Services.

Perry, M., & Sanderson, D. (1998). Coordinating joint design work. *Design Studies*, *19*(3), 273–288.

Perttula, M., & Sipila, P. (2007). The idea exposure paradigm in design idea generation. *Journal of Engineering Design*, *18*(1), 93–102.

Pfeifer, R., & Bongard, J. (2006). *How the body shapes the way we think. A new view of intelligence*. Cambridge: MIT Press.

Purcell, A., & Gero, J. (1996). Design and other types of fixation. *Design Studies*, *17*(4), 363–383.

Ralph, P., & Wand, Y. (2009). A proposal for a formal definition of the design concept. In K. Lyytinen, P. Loucopoulos, J. Mylopoulos, & W. Robinson (eds.), *Design Requirements Workshop: a Ten Year Perspective* (pp. 103–136). Berlin, Ge: Springer-Verlag.

Ramduny-Ellis, D., Dix, A., & Evans, M. (2010). Physicality in design: An exploration. *The Design Journal 13*(1), 48–76.

Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annual Review Neuroscience*, *27*, 169–192.

Rittel, H. W., & Weber M. M. (1984). Planning problems are wicked problems. In N. Cross (Ed.), *Development in design methodology* (pp. 136–144). Chichester, UK: Wiley.

Salo-Mattila, K. (2014). Plane and space in pattern design. *Techne Series: Research in Sloyd Education and Craft Science A*, *21*(1), 1–21.

Shepard, R., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science*, *171(3972*), 701–703.

Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2001). Composition and construction in experts' and novices' weaving design. *Design Studies, 22(1)*, 47–66.

Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2000). Visualization and sketching in design process. *Design Journal, 3(1)*, 3–14.

Silvestri, C., Motro, R., Maurin, B., & Dresp-Langley, B. (2010). Visual spatial learning of complex object morphologies through the interaction with virtual and real-world data. *Design Studies*, *31*(4), 363–381.

Simon, H. A. (1990). *The science of artificial* (3rd ed.). Cambridge, MA: MIT Press.

Simon, H. A. (1977). *Models of discovery*. Dordrecht, The Netherlands: Reidel Publishing Company.

Speed, A. (2010). Abstract relational categories, graded persistence, and prefrontal cortical representation. *Cognitive Neuroscience*, *1*(2), 126–137.

Spence, C., & Gallace, A. (2007). Recent developments in the study of tactile attention. *Canadian Journal of Experimental Psychology*, *61(3)*, 196–207.

Suwa, M., & Tversky, B. (1997). What do architects and students perceive in their design sketches? *Design Studies*, *18(4)*, 385–404.

Varela, J., Thompson, E., & Rosch, E. (1991). *The embodied mind*. Cambridge, MA: MIT Press.

Vingerhoets, G., de Lange, F., Vandemaele, P., Deblaere, K., & Achten, E. (2002). Motor imagery in mental rotation: An fMRI study. *NeuroImage 17(3)*, 1623–1633.

Witt, J., Kemmerer, D., Linkenauger, S., & Culham, J. (2010). A functional role for motor simulation in identifying tools. *Psychological Science*, *21(9)*, 12–15.

http://dx.doi.org/10.7577/formakademisk.1481

Camilla Groth

Design and Craft Thinking Analysed as Embodied Cognition

Abstract

Through the concept of design thinking the act of designing is presented as an intellectual activity, and the act of planning the design is elevated over the making process. However, the importance of materiality and the embodied sense-making that occurs in this context should not be forgotten. In this study, embodied cognition in design and craft practices was investigated through three case studies. The study takes on an enhanced tactile perspective as a methodological platform; thus, the cases involve 1) deafblind makers in ceramics, 2) a practice-led self-study report on tactile experiences while working with clay and 3) a study on design students' use of their tactile sense during material exploration. The results show that the act of thinking design involves the body as a knowledge provider.

Keywords: design thinking, craft, practice, embodied cognition, case study.

Introduction

While research in interaction design for some time has utilised the theory developed within embodied cognition in relation to tangible interfaces (Dourish, 2001; Hornecker & Buur, 2006; Höök, 2010; Hornecker, 2011; Trotto & Hummels, 2013; Hummels & Van Dijk, 2015; Wilde, Tomico, Lucero, Höök & Buur, 2015), this theoretical framework has only quite recently been touched on within general product design or craft research (for examples, see Poulsen & Thorgensen, 2010; Rompay & Ludden, 2013; Rompay, Hekkert & Muller, 2005; Fredriksen, 2011; Kangas, 2014; Ojala, 2013; Tin, 2013; Nimkulrat, 2009, 2012; Ramduny-Ellis, Dix, Evans, Hare & Gill, 2010) and has been slow to influence the concept of design thinking. Moreover, the term 'Design Thinking' (Brown, 2009) has become ambiguous, since the latest developments have furthered the concept towards a business and organisation innovation method (Kimbell, 2011). What was traditionally understood as a study of the cognitive processes of the designer (i.e. design cognition), Design Thinking is now more popularly seen as a way to understand customer needs through the use of methods from design practice (Kimbell, 2011; Johansson-Sköldberg, Woodilla & Cetinkaya, 2013). Although conserning the same concept these separate directions may be described as two distinct discourses (Johansson-Sköldberg et al. 2013).

This article refers to the traditional understanding of the term, and it is extended to include the making of artefacts as well as the planning of designs. Traditional research in design cognition (Cross, Christiaans, & Dorst, 1996; Cross, 1982, 1984, 2001, 2011; Dorst, 1995; Dorst & Dijkhuis, 1995; Purcell & Gero, 1998; Akin, 1997; Akin & Lin, 1995; Rowe, 1987; Goldschmidt, 1995, 1997, 2001) has developed models around problem solving and strategies for framing the 'wicked' (Rittel & Weber, 1984; Buchanan 1992) or ill-defined (Goel & Pirolli, 1992) design problems (for an overview see Seitamaa-Hakkarainen et al., 2016 in this special issue.) Designing is thus presented as a predominantly intellectual activity, in contrast to its practical nature. This view, although plausible in the way it portrays the designer as a thinker, separates designing and making into two entities, leaving making behind as merely part of the implementation phase. Making or crafting the design idea is thus situated at the end of the design process (Cross, 2011, p. 4), seemingly not requiring intellectual activity.

However, the act of *making* is still an integral part of design and craft practices

(Nilsson, 2013). As the theory developed within design cognition studies are refered to when describing both the designer's and the craft practitioner's design process, it is necessary to develop it to include also the more material based aspects that recuires embodied sense-making. Similar critique has been aimed at both discourses of design thinking by design researcher Lucy Kimbell, (2011).

The results of this study suggest that the physical making and crafting of a design involves the embodied mind. It further claims that also the act of *thinking* or planning a design likewise depends on accumulated embodied knowledge. Through our physical experiences of the material world, we create mental images that we rely on in the design process, thus the body provides information also in the planning phase of designing, even before material manipulation (Groth & Mäkelä, 2016). The philosophical theory on embodied cognition (Merleau-Ponty, 1962/2010; Johnson, 1987, 2007; Varela, Thompson & Rosch, 1991; Lakoff & Johnson, 1999; Noë, 2004, 2009) supports this notion as it includes the perceiving body in sense-making and claims that human cognition is dependent upon its interaction with its environment, thus pointing to action and perception as keys in knowledge formation.

While literature on design cognition also mentions reflective conversations with material or reflecting-in-action and reflecting-on-action as proposed by Schön (1983), the role of the body and embodied knowledge is not elaborated on in this context, other than in terms of tacit, implicit or experiential knowledge. Although describing a very similar way of engaging with materials, these concepts do not clearly articulate the body as a contributor to knowledge.

Only recently the theory of embodied cognition has been recognised in the field of design and craft. Cognitive scientist and design researcher Henrik Gedenryd (1998) criticises design cognition studies and claims that they follow a traditional research paradigm with a focus on the isolated mind and intramental processes rather than taking into account perception and interaction with the environment (Gedenryd, 1998, p. 8). He further argues that "designers go to some length to even avoid having to work intramentally, as the usual theories claim they should do" (Gedenryd, 1998, p. 17).

However, there remains a lack of a comprehensive empirical model for how the designer or craft practitioner uses his/her embodied knowledge in his/her design or making process. This is understandable, as the topic is not easily approached. Any skill or prolonged practical knowing involves a great deal of tacit knowledge that is not explicable (Polanyi, 1958; Niedderer, 2007; Biggs, 2004), and this makes the subject difficult to research (Niedderer & Townsend, 2014). In addition, embodied cognition theory has only recently gained credibility and thus developed quickly in the recent decennium. Although traditional design cognition theory has a line of discourse close to phenomenology it has not been as articulate on the aspects of materiality and subjective bodily experiences of the practitioner.

Another reason for this gap in knowledge might be that design practice, and especially crafts, have tended to be researched from outside the practice itself. Although benefiting from these studies, the research done in the workshop provides another perspective (Keller & Keller, 1996, p. 21). Now that designers and craft practitioners are also included in higher academia, they have the opportunity to conduct organised research on their own practice. The researcher-practitioner has an intrinsic motivation to reveal his/her experiential and embodied knowledge; thus, design and craft research gain access to the practitioner's point of view (Groth, Mäkelä & Seitamaa-Hakkaraien, 2015, p. 57).

Erin O'Connor is an example of a practitioner who has researched her own craft practice through examining the embodied and experiential aspects of the process. She trained as a glassblower for two years while reporting on her learning experience through very vivid accounts of her personal experience (O'Connor, 2005, 2007). Another example is a group of metalsmiths (Almevik, Jarefjäll, & Samuelsson, 2013) who physically re-enacted the sequence of a video documentary on metalsmithing from the 1970s in order to understand the making process of an object. By re-enacting the process themselves, they were thus also able to reflect on their own haptic and experiential knowledge of the same process. The research at hand is a contribution to this growing tradition of researcher-practitioners who research their own practice, through practice and for practice, with an emphasis on the haptic and embodied aspects of the design and craft process.

Although not yet defining a model, this research presents some initial findings of embodied sense-making in the process of handling material in a design or craft context. The guiding research question is: *How do design and craft practitioners think through their hands?* Being a relatively poetic question, some may feel that its logic is questionable: thinking happens in the brain, hands do not think. Yet anyone who works with material by hand may identify with the notion of some of the sense-making happening through the making process, via the contact with the material and through the hands rather than only in their minds (see Poulsen & Thorgensen, 2010, p. 30).

In the field of crafts, a sense of *thinking through material* has already been acknowledged in research (Anttila, 2006; Mäkelä, 2007; Nimkulrat, 2009, 2012). The research position that I take is therefore not a critical one; I am not questioning whether there is a notion of thinking through the hands within the practice of design and craft. Rather, I seek to investigate *how* embodied cognition is enacted through practice in order to better understand the relationship between the embodied mind and making in material.

Methodically, this research takes the perspective of an enhanced tactile experience as the platform for investigation in order to highlight the bodily aspect of the design and craft practice. The research may be seen as a sensory ethnography as outlined by visual anthropologist Sarah Pink (2009), although it focuses on the haptic viewpoint rather than a fully multisensory point of view. To be able to research such tacit knowledge, it was necessary to use multiple methods, such as participatory workshops, ethnographic and auto-ethnographic methods (Ellis & Bochner, 2000) as well as qualitative content analysis of interviews and video material. The research was conducted using a multiple case study research design (Yin, 2009).

I first arranged a series of workshops with deafblind makers in ceramics. The aim was to study the context of making in an enhanced tactile setting, learning from people who would be true experts in the use of their tactile sense. Having gained experience and inspiration from these participants, the next case involved a practice-led self-study in which I spent several days blindfolded in my studio throwing clay cylinders on a potter's wheel. This was done in order to reflect on my own experiential knowledge, which was more easily available due to the blindfolding. In particular, aspects related to tactile knowing and emotions that were present at different stages were useful for the investigation. The last case involved a study of students' use of their tactile sense and embodied knowledge in their material exploration, design and making process. From two groups of 19 students in total, two students were studied closely and interviewed for this research, and their own documentations, diaries and artefacts were analysed.

The research shows aspects of embodied cognition in these three settings and emphasises the need for a continued research effort into embodied cognition in the field of design and craft. As a result of this research project, I found that embodied cognition theory lends itself well to informing design and craft research since much of knowing is situated in action and in relation to previous experiences and material skills. Thinking design relies upon these embodied skills; therefore, the conceptual separation between making and thinking in design is not realistic. In the following section, the theoretical framework is introduced and the three cases are described, followed by a discussion on the findings.

The Knowing Body

The crafting and making process provides us with an opportunity to investigate the interaction between material and the embodied mind. In this research, extra emphasis is placed on experiential knowledge by including the body as a knowledge-provider in practice. To be able to research this body-based knowledge, it was necessary to adopt a theory that supports this type of meaning making.

Embodied cognition is grounded in phenomenology, which is the philosophical strand that most strongly argues for the knowing body. In contrast to the Cartesian dualistic and hierarchical view of the mind and body, phenomenology claims that we are restricted to a view of the world seen from the perspective of our situated body, thus we perceive the world through our senses. However, through our ability to move our body to a new position we may perceive the world from a new perspective. Thus we accumulate knowledge through interaction with our environment. This theory has been taken further by writers such as Maurice Merleu-Ponty (1962/2010) who specifically elaborates on perception in relation to meaning making and, more recently, Mark Johnson (1987, 2007), George Lakoff and Mark Johnson (1999), who show how the embodied mind is revealed through language and image schemata.

As we are now talking about the way we *think* or make sense in design and crafts, cognitive neuroscience also plays a part. Enactivism is a philosophical strand of neuroscience that has embraced the idea of the embodied mind. The orientation suggests that a person learns in action and accumulates knowledge through his/her embodied experiences with his/her environment; thus, the body is fundamental in all knowing (Varela et al., 1991; Noë 2004, 2009). This means that we create our minds through our experiences, and the more experiences we have of a certain action or interaction, the better we are able to anticipate and predict possible outcomes from future similar actions and interactions. Many aspects of design and crafts based knowledge can be explained by the theory of the situated and embodied mind, especially when it comes to material exploration and manipulation. In this context, the practitioner is using her embodied preknowledge of these materials.

Three Case Studies

The case study methodology developed by Yin (2009) has been used as a frame and general design for this research, yet each case uses a variety of methods. The *multiple* case study methodology was chosen in order to study three aspects of the research question in parallel. This allowed me to first visit a group of makers with a special condition, then to investigate the same research question from an auto-ethnographic perspective, and finally to visit a group of students, thus gaining three different perspectives and environments for the same research question. The point is not to compare the cases but to show different aspects of the same issue: How design and craft practitioners think through their hands.

Case 1: What can we learn from experts in tactile knowledge?

The first case involves three ceramic workshops with deafblind makers conducted at the IIRIS Service and Activity Centre for the visually impaired in Helsinki and the Tampere Resource Centre for the Deafblind. The main task of the study was to investigate unique processes related to creative working in a setting where the tactile sense is enhanced. The workshops were followed up by a discussion seminar at the IIRIS Centre, where aspects of embodied knowing and the "abstract" were explored. Two to six participants were usually present in the three workshops and the seminar, all with differing degrees of dual modality impairment. They brought their translators, and some also brought a personal assistant. All communication was thus translated using either tactile sign language (Figure 1), sign language or aided by an inductive hearing aid.

Figure 1. Tactile sign language. This image shows how one of the participants communicates with his interpreter through tactile sign language. (15 May, 2012. Screen shot from the video by the researcher. The participant has agreed to his image being used).

During the video- or audio-recorded workshops, I asked semi-structured questions in situ; this was done in order to gain accounts on the participants thought processes while working. Due to the difficulty in communication, these workshops intuitively became participatory workshops, especially the one in Tampere (Groth, Mäkelä & Seitamaa-Hakkarainen, 2013). I decided to use my own hands in the making of ceramics together with one of the participants as this was the most direct and useful way to communicate at that moment.

The participant wanted to try throwing clay on the potter's wheel, but I needed to communicate the instructions for throwing to him through his interpreter. Since the participant needed his hands to communicate through the tactile sign language and his hands were busy with the clay, I started throwing the clay *with the participant's hands*. I then discovered that in the act of throwing clay, tactile communication was sufficient to pass over my embodied and tacit knowledge about the throwing practice to the participant (Groth et al., 2013). The participant later tried throwing clay by him self and was unusually successful in his attempt.

Following the workshops and discussions with the deafblind participants, I learned that they had gained a new ability, which some of them reported to be very positive. They gave various accounts of how they used their haptic and tactile sense in their everyday life, from measuring the size and weight of objects to communicating with their loved ones. Some of the deafblind reported on a new relationship with their bodies, having become braver in their use of touch. This was also clearly noticeable in their brave way of handling the clay material.

Inspired by these workshops and the enactivist theory, I created a new research setting in which I sought to enhance my own tactual skills and sensitivity in order to research the possible benefits. The underlying theory was the plasticity of the brain and the assumption that the brain reorganises itself according to our actions in order to enhance the skills needed for repeated actions, an ability thought to help in skill learning.

Case 2: Tactile augmentation in ceramic craft practice

The second case involved a practice-led self-study on tactile augmentation in ceramic craft practice. I documented a five-day blindfolded working process, developing a method for studying sensory experiences, haptic and tactile experiences in particular. The main task during the throwing process was the ability to judge the shape and form of the piece using the hands only (Groth, Mäkelä & Seitamaa-Hakkarainen, 2015, p. 59). The aim was to throw a cylinder that would meet the general technical requirements within ceramic craft practice.

In order to document the event and the sensory experiences, I made use of several research methods: firstly, a diary method was used, in which I answered specific questions and prompts just before starting the throwing session, and again just after finishing. Secondly, I used a contextual activity sampling system called Cass Q (Muukkonen, Hakkarainen, Inkinen, Lonka, & Salmela-Aro, 2008), which allowed me to create a portable questionnaire that was completed on a mobile phone before and after the event; it also allowed for the inclusion of images or videos if necessary. Thirdly, a video camera was used to record the event; this was also used for recording think aloud accounts (Eriksson & Simon, 1993). This meant speaking to the camera and trying to explicate everything that I was thinking and doing that could possibly be related to the event (Figure 2).

Figure 2. Blindfolded and thinking aloud. This is a screen shot from the video during the throwing events. (12 April, 2013).

The act of blindfolding helped me to reflect on the haptic experiences of the throwing situation, which usually go un-noticed. I experienced that my tactile skills were enhanced over the five days, and on the last day it felt quite natural to trust my hands in the throwing process.

More importantly, I also noticed that the feel of the clay and the conditions of the material affected my emotions in either a positive or negative way. For example, when conditions started becoming unfavourable and the clay was getting too wet and soft to shape anymore, this was experienced as a negative emotion, and I knew that the available options for action were reduced and a decision had to be made whether or not to pursue certain actions or whether these could be considered too risky (Groth et al. 2015, p. 76). This indicated that emotions guided me in my risk assessment and decision-making during the process, and thus they also guided me in the problem-solving processes.

As emotions were initiated through the manipulation of the material, I made the hypothesis that emotions were guiding the throwing process to a large degree. In order to investigate this aspect further, I made a new separate video analysis (Groth, 2015) using the *Interact* video analysis software. I specifically analysed the so-called 'critical incidents' (Flanagan, 1954); these are the situations in which the process is in some way changing direction or is being jeopardised in some essential way. All video material (10 hours) was initially analysed to detect the critical incidents of the throwing events; this came to 23 critical incidents over the five days of data collection.

When analysing the video data, it became clear that the critical incidents had different degrees of severity. Some were not very severe and the problems were solved easily while others were of a more serious kind. The incidents were also either expected or not expected, some started abruptly and some were developing over time.

The haptic or tactile experiences that were found in the analysis of the critical incidents were to do with the density of the clay material, i.e. how hard or soft it was, and the wetness of the surface, i.e. the stickiness of the clay at different times during the throwing process. Also the position of the clay on the wheel, if centred or not, was a clear factor in the critical incidents and that would affect emotions in a negative or positive way. When it came to emotions, the most central were to do with confidence, stress levels or spirits, such as high or low) (Groth, 2015). The video analysis software gave me the opportunity to link the tactile experiences to the felt emotions and actions (Figure 3).

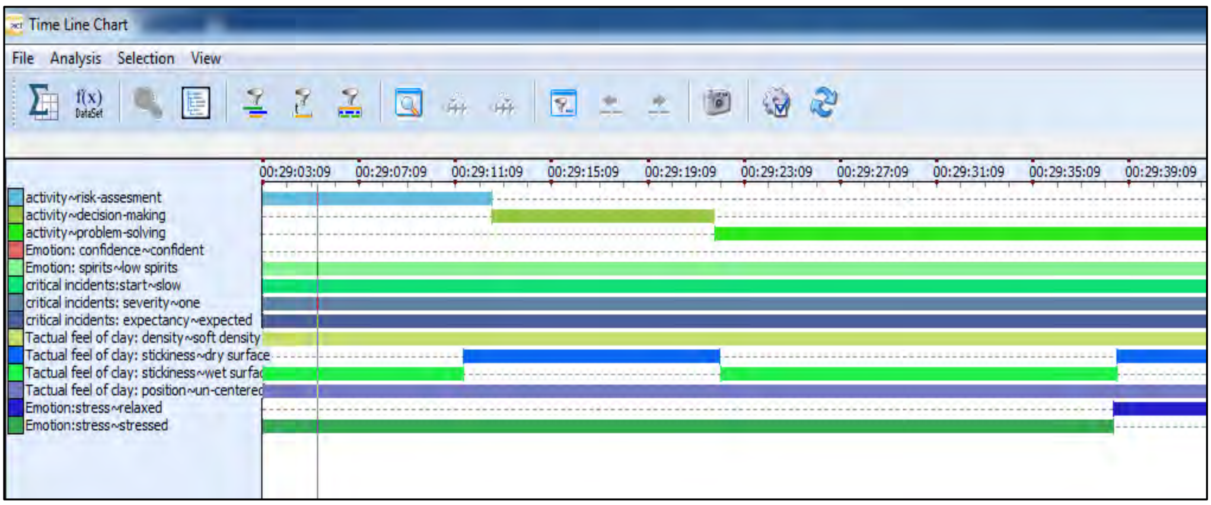


Figure 3. Tactile experiences and related emotions and actions. A screen shot from the video analysis process showing the timeline of a slow starting, severity one, critical incident, and with tactual experiences coupled with actions and emotions.

Case 3: The role of the knowing body in design students' material exploration

The third case was examining students' use of their tactile sense during a design and material exploration process. For this research, data gathered from the Design Exploration and Experimentation course given at the Department of Design in Aalto University was utilised. Each year, around 12 Master degree students participate in an eight-week intensive course. During the course the students travel to another city or area in Finland to gather inspiration; they also document their process in working diaries that they share in their weekly reflections (Groth & Mäkelä, 2016). Finally, an exhibition is arranged that shows the produced designs and artefacts from the course.

Data from 19 students was gathered and from this data, two students' cases, whose work was closely linked with the theme of tactile experiences, were chosen for deeper analysis. The data consisted of the students' diary notes, their drawings, photographs, weekly reflections and the final reflections produced during the courses (Groth & Mäkelä, 2016). The two students were also interviewed. The analysis was conducted according to a thematic content analysis (Fereday & Muir-Cochrane, 2006).

One of the students put great effort into finding the right "feel" of material that would fit her purpose. The emotional feeling that the finished piece should awake in the audience was a feeling of disgust and meanness, but also of wealth and luxury (Groth & Mäkelä, 2016, p. 12). The student made four physical models in velvet, satin, leather and plastic (Figure 4). In the interview, she describes these tests as her most important material tests as, they were used to test and compare the tactual experience and feel of the materials.

Figure 4. Four material tests made by the student. Photo by the researcher.

She explains further that they aided in evaluating the emotional connotations of the materials as she was able to let her friends and fellow students feel and evaluate the materials and in this way also confirming the social and ethical value and general understanding of the material (Groth & Mäkelä, 2016, p.12).

The other student explored the different connotations of materials when used in unconventional contexts; testing the embodied expectations of the different materials (Figure 5).

Figure 5. Knives in different materials made by the student.
Photo by the researcher.

A mental material exploration was detected to precede the physical material exploration. In their diaries, both students list materials that they try out in their imagination before deciding which materials to try out physically (Groth & Mäkelä, 2016, p. 16). In the interview, one of the students reports that she actually did most of her material exploration in her head. Without previous bodily experiences of these materials, there is no pre-knowledge to judge these experiences against; therefore, we may assume that she was reverting to her experiences of these materials that she had gained in other, previous contexts (Groth & Mäkelä, 2016).

Both students chosen for the interview and deeper analysis had backgrounds in other craft practices, metalsmithing and textiles, before joining the University. Their previous skillset set them apart from some of the other students, who had less or no previous experience with handling materials in a design context. Students with less embodied experience with materials had more difficulty in choosing materials, and they became frustrated with their design process even before their actual material exploration.

In the case of one student, the awkwardness of moving into the material realm hindered him from advancing his design from drawings and concepts into a material prototype. In a video-recorded workshop session taken during the course, the student talked about his frustrations with materials as the reason for not being able to progress. He said: "my hands were not skilled enough to manipulate the material," and he later said, "I could not make what I wanted, so I made something else" (Groth & Mäkelä, 2016, p. 18). This particular student did not come to terms with the changed image of what he wanted to make, but instead repeatedly restarted his project, and he felt continuously frustrated through the entire course.

Discussion

The three case studies provided an opportunity to first gain inspiration and a deeper understanding from experts in tactile knowledge, then to turn the attention inwards to study one's own experiences in making, and lastly to turn the gaze outward again to study what the findings mean for design students. Although quite different settings, these three cases all focus on tactility and the body as an informant in sense-making with a material.

The general research question was to find out how design and craft practitioners think through their hands, and the specific research questions for each case were:

Case 1: How do experts in tactile knowing use their enhanced tactile sense in a making situation?

Case 2: a) What methods may be used in the study of embodied and experiential knowledge in crafts? b) What is the role of emotions in connection to tactile experiences in a craft practice?

Case 3: How do design students use embodied knowing in material exploration?

How do experts in tactile knowing use their enhanced tactile sense in a making situation?

Case 1 highlighted that sensory experiences or skills may be developed and augmented through an impairment of another sensory modality; this made me realise that although the making practices are predominantly tactile, we take much of our tactile experiences for granted, and that we have much to gain by listening to our sensory experiences. The deafblind makers may inspire research into embodied knowledge and the possibility of enhancing one's tactile sensitivity by closing one's eyes and exploring material from a new perspective.

The act of manipulating material is also a way of connecting oneself with the physical world; the following passage is from the analysis of the first case (Groth et al., 2013, p. 7-8):

> When we touch a material, we simultaneously feel ourselves and become aware of 'being'. In this sense, making can be considered a way of being in contact with oneself. Our body is in contact with a material that bends to our will, but the material also has its own will; thus, there is a struggle between our will and the material. We make concessions to the material and we make compromises with ourselves, due to the will of the material. It is as if there is communication with and through the material, and the outcome is an expression of this struggle or collaboration. Therefore, the outcome of this process is not a pure expression, but rather evidence of that process. In other words, it is an artefact that embodies the self and the material. This struggle was evident in both Olavi's and Laura's [deafblind participants in the research] processes as they familiarised themselves with, and eventually won the struggle with, the new material.

Emotions seemed to play an important role in the connection to the felt experience of material; this was an aspect that featured strongly in all three cases. In Case 1, emotions were connected to the deafblind participants' anxiety over technical skills as they embarked on working with a new material. The participants were new to the porcelain clay that was used in the workshop, and they expressed anxiety and a disbelief in their making abilities, as the material was difficult to use and did not comply with their previous experience of clay. When continued efforts with discouraging results finally became positive through an internal learning process, the emotions of the participants grew equally positive and a "catharsis" was experienced. This was usually linked with the acceptance of the new result even though it did not comply with the initial plans or mental image aimed at.

From experiencing tactile communication in the first case study, I would also like to point to the possibility of tactile skills being taught to another person by 'hands on' tactile instruction, even without the use of language. In some cases, this might even be more effective than only visual or vocal teaching methods, as deaf and blind Olavi (his name has been changed) was able to receive my embodied knowledge of the throwing process through us throwing together even though he could not see or hear anything during the process. The exact muscle and limb pressure and timing of the hand movements were conveyed from me to him entirely without language (Figure 6). As he got the idea of how to act with the clay, I could feel a gradual transition of him starting to lead the throwing process.

Figure 6. Olavi throwing clay while being aided by the researcher.
Screenshot from the video by the researcher.

What methods may be used in the study of embodied and experiential knowledge in crafts?

While participating in the making process with the deafblind, I also realised that it is not as feasible to study someone else's sensory experiences, as one's own. This is perhaps also why research on practitioners done by theoreticians can only come so far; research on practice is more feasibly conducted *through* practice, in a practice-led research setting, where the researcher and the subject of the research are the same person.

The study of experience also poses the challenge of trying to catch and store events that are fleeting and consists of moments that constantly change and involve multiple sensory modalities. The idea of blindfolding myself helped in studying and articulating my haptic sensory experiences and my embodied knowledge of the throwing process, but needed support from more traditional methods of researching practice. By combining different methods from the practice-led tradition, such as the diary method and general documentation of the working process, with methods such as an event sampling system and a video-aided protocol analysis combined with think aloud accounts, I managed to collect multiple types of data for my case (Groth et al., 2015).

After the data collection, the videos were analysed through protocol analysis, which means looking at each second of the video separately, noting both what was said and the actual action that was made. During this process, I felt that I knew more than I could say, at the time of making (Groth et al. 2015, p. 70). This notion is familiar from the concept of tacit knowledge (Polanyi, 1958). However, the protocol analysis provided the opportunity to reflect on the events in slow motion, without simultaneously having to control the material in a making situation. This elicited the need to add a column for reflections-on-actions (Schön, 1983) which included all the sensory experiences of the process and became the in-depth analysis of the event. I found this account the most informative as it was essentially a detailed description of my experiential knowledge, an account that could not possibly have been produced by an outside researcher, but only by the practitioner-researcher alone (Groth et al., 2015.)

The video was particularly useful in this research as it made it possible to reflect on actions in hindsight. Pink (2009, 2011, 2012) has used video extensively in her research, which aims to take the sensory realm into consideration. She has found that video enables the viewer to either recall previous experiences in a multimodal form if personally experienced previously, or to recall similar experiences if the videoed events are not subjectively experienced (Pink, 2012). This supports the findings in the research at hand as I was analysing videoes of events that I had experienced myself, but blindfolded; therefore, I had no visual memories of the events, but my sensory experiences were recalled through the recorded video footage. Emotions connected to these events were similarly revisited and were thus also available when later analysing the critical incidents of this case (Groth, 2015).

As with Pink's research, video was here found to be useful as a medium for researching knowing in action on three levels (Pink, 2012). Firstly, it was useful in collecting the data in the form of moving images connected with the audial reference, as I was able to revisit the lived experience of the event and thus tap into my embodied memories of the event. Secondly, the video was useful in the way it could be analysed in slow motion, be reversed and skipped forward in order to take multiple actions into account and to distinguish critical incidents for separate analysis. Thirdly, the video has been effective in presentations of the research, as it also provides a situated and multisensory experience of the research events to the audience, who can better understand the sensory experiences involved by relating to their own embodied knowledge of similar previous experiences, or imagine such experiences.

What is the role of emotions in connection to tactile experiences in a craft practice?

Touch was linked to emotions in all three cases of the study and in different contexts. Emotions have been connected to sensory experiences, and even decision-making, in for example cognitive science (Damasio, 1994, 1999). However, the way that the tactual feel of the material affects emotional feelings in the process of making is perhaps known to practitioners, but little elaborated on in research. Emotions have previously not been seen as valid informants in research practice, or even in craft and design research (Niedderer &

Townsend, 2014); however, researchers in design have recently begun to include this aspect. Through this investigation, it seems that emotions also play a part in the manipulation of materials.

The second case study made me particularly aware of how emotions linked to tactual experiences served as contributors to risk assessment, decision-making and problem-solving in the making process. Therefore, emotions seem to guide the progress of the making situation, especially when the material qualities and affordances vary and a successful outcome depends on the embodied knowledge of the maker. This passage is taken from a previous article describing the tactile experiences in Case 2 (Groth et al., 2015, p. 76):

> When throwing clay walls, the only part that touches the clay surface is the tip of the fingers. Through these, the practitioner receives sufficient information on the orientation of the work, the temperature, the resistance of the material and the wetness or softness. These haptic experiences directly provide a feel or a feeling of the working conditions and the possibilities available in working the material. These conditions and affordances may change within seconds, so an update of the conditions at hand is continuously made through the sensory points of the fingertips.

In order to investigate this aspect further, I carried out a renewed analysis of the videos collected during the throwing sessions, this time using the *Interact* video analysis software, which enabled me to fully explore the experience of throwing clay, to pick it apart in its details and see what kind of different aspects and new insights arise from this kind of analysis.

The tactile experiences that were found to be important in knowledge formation during the throwing process involved the density and surface structure of the clay and the positioning of it on the throwing board. Key emotions involved levels of confidence and stress together with high or low spirits Activities that were tagged in the videos were risk assessment, decision-making and problem-solving (Groth, 2015).

I found that during critical incidents, feelings of low spirits and stress were present, together with certain conditions of the clay, in risk assessment, decision making and problem solving during the throwing process. However, I found that these negative emotions were actually helping the process by aiding concentration and focusing on solving the problem at hand. The heightened alertness that the stress and worry about the risky moment in the process involved gave that extra sensitivity and attunement to the material that the successful handling of the critical incident demanded.

Emotions were also frequently aired in the think aloud accounts that facilitated the analysis process. Even claims of fear emerged in the accounts as the process was approaching a risky phase or in sudden critical incidents (Groth, 2015). Emotions as guides in decision-making are familiar from Antonio Damasios' (1994, 1999) work in cognitive science, and he is often connected to the field of embodied cognition. One of Damasios' claims is that *gut feelings* generate emotions that guide us in intuitive decision-making, (Damasio, 1994, p. 169 & 173), and he calls this the "somatic-marker hypothesis" (Damasio, 1994, p. 175). Soma means body in Greek and Damasio links the somatic markers to the theory that emotions are important in risk assessment as they help in our survival (Damasio, 1999, p. 42). This aspect is supported by researchers studying the function of emotions (Keltner & Gross, 1999, p. 472). Mark Johnson (2007) builds on Damasio and elaborates on emotions as the most essential way of making meaning out of our experiences: "emotions are processes of organism-environment interactions. They involve perceptions and assesments of situations in the continual process of transforming those situations." (Johnson, 2007, p. 66-67). As a result of this case study, making in a material can be seen as continuous risk assessment, including constant decision making and problem solving, and emotions seem to guide the progress of the making situation (Groth et al., 2015, p. 76).

How do design students use embodied knowing in material exploration?

The two students that were studied closely in the third case were using their tactile sense in various situations during their creative process. The tactile aspect of the materials and the use of touch were important on many levels, but especially in the process of deciding which materials to use. The felt experience of materials was also linked to emotions and shared social and ethical values.

Physical touch played an important role in the decision-making process as it confirmed the imagined image of the material. In the interview, one of the students explicitly says that vision provides only half of the perceptive view, and that touch fills in the missing part (Groth & Mäkelä, 2016, p. 17). Touch was seen by both students, as the main means of evaluation when they made choices on what materials to use, or in evaluating the quality of a material.

In addition, the felt experience of physically working the material affected both the students' self-esteem and image of themselves in addition to their relation to the making process. Both students experienced new materials in their exploration process for their designs, and the new material behaviour disrupted their workflow and made them question their identity as makers, similar to the case with the deafblind participants. The students' anxiety was overcome through resorting to familiar patterns of solving material problems known to them from other domains.

In all three cases, the deafblinds, the single practitioner and the design students, we see a pattern of mental discouragement when material conditions become unfavourable and, similarly, how adaption through referring to previous experience overcomes difficulties. In design cognition studies, the concept of scaffolding (Wood et al., 1976; Puntambekar & Hubscher, 2005) is referred to when discussing novices' learning process using their social network as building blocks in learning situations. However, previous bodily experiences are also important in this context, as found by design researcher Biljana Fredriksen (2011). Fredriksen (2011) argues for the embodied knowing that is built up by physical interaction and that is relied on in new material encounters.

The way of creating mental images (Kosslyn, 2005) of materials and mental rotation (Purcel & Gero, 1998) is also familiar from design cognition studies, but the use of the body as informant, or embodied cognition, is seldom elaborated on in this field of design research. However, when confronted with a spatial problem in her two-dimensional design, one of the students built a three-dimensional model in order to be able to see the imagined design from different angles and to measure the intended material over the model. She described this physical exercise as necessary because her imagination was not enough to create the design only in her mind or even on paper through drawing (Groth & Mäkelä, 2016).

As seen in this student's case, her mental rotation of the imagined design was aided through taking the design into the lived experience by the building of a physical prototype, using techniques learned in her previous profession. Both students had acquired sedimented knowledge (Keller & Keller, 1999) during their practice in other domains that emerged in a new domain, and this allowed them to progress in an otherwise stagnated design process.

In design cognition research in general, it has been found that sketching is closely linked to the designer's thinking process (Goel, 1995; Purcell & Gero, 1998; Seitamaa-Hakkarainen & Hakkarainen, 2000). Through drawing, the designer is able to externalize the imagined design (Cross, 2011). Similarly, the craft practitioner's modelling or prototyping directly with her material may be seen as a way of thinking through the interaction of hands and material, body and environment. This was clearly to be seen in the students' way of working, as well as the deafblind makers' working in clay, in which the option of making a sketch was not available.

One of the deafblind workshop participants even said that she would quite often start her process by picking up the material in her hands, and then by moulding and working it she would find her way to her design idea. Modelling in clay resembles sketching and, as such, may be seen to contribute to thinking through the hands, in a similar manner to how drawing is generally understood, but in three dimensions (Groth et al., 2013). Design researcher Nigel Cross (2011, p. 4) notes:

> In traditional, crafts based societies the conception, or 'designing', of artefacts is not really separate from making them; that is to say, there is usually no prior activity of drawing or modelling before the activity of making the artefact. For example, a potter will make a pot by working directly in clay, and without first making any sketches or drawings of the pot.

Both students also claimed that they found drawing different materials from memory useless when it came to research on material properties. Instead, it was important to obtain a sample of the different materials to be able to investigate and compare the materials physically (Groth & Mäkelä, 2016, in press). Although drawing is indisputably important as a thinking tool for designers, it is difficult to use drawing in the exploration of material choices. Here, physical touch seems to be crucial. A skilled draftsman may be able to reproduce convincing reproductions of a material visually, but to draw materials' physical properties from one's memory is rather challenging. A drawing, even computer aided, gives only a poor sense of weight, density, flexibility, temperature or surface structure.

As the material choice, the mental image of a design and the ability to judge material properties based on previous experiences are all important aspects of design work, the use of touch and related embodied cognition is an issue of great importance in design research as well as in design and craft education. This reflection is supported by psychologist Akter Ahsen (1984) who has investigated mental imagery and came to the conclusion that a mental image is dependent on physical experiences in the meaning making of mental images in relation to the real world (see also Laamanen, 2016, p. 45).

Real world material manipulation has been noted as also being important in the context of education, as sensory-motor interaction with the environment during learning results in more endurable and richer knowledge (Kiefer & Trumpp, 2012, p. 20). As a result of this case study, I would emphasise that design thinking involves embodied cognition as well as making practices, thus it should not focusing on merely the intramental abilities of the designer. Design students benefit from embodied material explorations of multiple kinds in order to more realistically form a mental image of an envisioned design, already in the concepting process.

Emotions were present in all three cases

The word *feeling* as in tactile sensations and *feeling* as in felt emotions merged in the students' descriptions of their sensory and emotional experiences. The way something feels (tactile) seems to affects the way we feel (emotional). The students also used this aspect in their careful selection of materials (Groth & Mäkelä, 2016). We have many shared notions of the feel of materials that are triggered as mental images even when only mentioned in speech (Groth, 2015, p. 12). In the first student's case, emotions are connected to the atmospheres and images that the felt experience of certain material connects to. In the second student's case, it was a more about emotions of discomfort or confusion towards the 'right' or 'wrong' feel of a material, and his project plays with this notion. As with the deafblind subjects (Groth et al., 2013), also in the second case study (Groth, 2015, p. 12), positive or negative emotions were connected to the tactile feel of the material:

> (…) the feel of the material as it is actually touched gives us both the tactile feel and emotion, and thus also the anticipation of what this material has to offer us. For an experienced ceramist, the density of a bit of clay immediately gives an idea of its possible uses, together with an either positive or negative background feeling simultaneously. If the clay is too hard, it is not good because it cannot be easily handled and needs to be soaked. If the clay is too wet, it is also not good and it needs to be dried until workable. A perfectly smooth and dense bit of clay gives a good forecast for any project, and it is therefore experienced with positive emotions.

In general, the tactile feel of materials seems to affect emotions in multiple ways. Impressions of materials carry shared cultural notions, as noted in the case of the design students. As one of the students confirmed her notion of the materials by testing them with her fellow students, we can suppose that designers share general emotion-based notions, not only mental images, but also *mental impressions of tactual experiences* of materials. These findings are similar to those in research by Zuo et al. (2001); they claim that not only physical but also cultural and psychological response and expectations are attached to material properties.

Similarly, Karana, Pedgley & Rognoli (2015) emphasise the experiential perspective and the fact that material interaction occurs through our senses. They describe materials as actors that play roles that the designers have assigned to them (Karana et al., 2015). They also point out that: "Deciding on the role that a material will play in an artefact is one of the creative challenges that designers face" (Karana et al., 2015, p. 17-18). These decisions seem to involve the previous embodied experiences, and emotions, of the designer.

Implications for design education and the concept of design thinking

The field of design has changed drastically in the last two decades and has now increasingly moved also beyond the material realm; thus, design education likewise has to change. The focus is no longer on material manipulation and the relationship between the maker and material as in the field of crafts. The field of craft has also changed, and aspects of communality and sharing have come to the fore. However, as we as human beings continue to be physical, we will always have physical needs, and part of the designer's or craft practitioner's task will still be to improve and develop material objects for physical use.

The present study contributes to the area of design education by highlighting aspects involving embodied cognition in design and to encourage the inclusion of the body as knowledge provider in the study of the way designers think. When the material exploration, prototyping, crafting or production of a design is moved too far away from the design thinking process, there is a risk of the end product lacking in material quality. Ultimately, this will affect the success of the product. In this context, the design student needs to acquire good skills and an embodied knowledge of materials and technical processes simply to be able to construct a design in his or her mind.

Conclusion

The main contribution of this research is the perspective on the making process, here seen from an enhanced haptic point of view. I found that the body and emotions related to physical interaction with material were important informants during designing and making, especially in the many different aspects of decision-making that the designer or craft practitioner goes through.

Sensory experiences are keys to sense-making in material manipulation. What is seen by the eye is confirmed by touch, and through our hands we are able to interact with and test the material, learning by doing and acting; thus we also shape our minds and affect our future actions with similar or new materials. Emotions related to touch experiences become knowledge that the designer relies on. Previous embodied interactions play a key role in design students' understanding of new material experiences and are relied upon in the choice of materials and techniques during future design processes.

Tactile aspects are important in the evaluation of materials for design, even when forming mental images of tactile experiences. Imaginary material exploration and mental images of physical experiences are based on previous bodily experience of materials, and the body and sensory experiences play a role in the sense-making process. Tactile- and material-based forms of education are therefore key to learning in the field of craft and design as experiential knowledge may only be acquired through situated and embodied interaction with materials. Embodied, emotional and even ethical and social aspects of the materials' properties play a role in the designer's judgement and selection of materials. Some of these notions are shared embodied knowledge that consequently also plays a part in the communication between designer and user.

The practice-led research setting, including the multi-method developed for this study (Groth et al., 2015) was found useful in explicating the personal knowledge and sensory experiences as well as related emotions during the making event. The studio-as-research laboratory and the practitioner-researcher's subjective perspective allowed for a reflection on experiential knowledge that is impossible to uncover in a distant and objective research setting. As emotions were also found to be major contributors to risk assessment, decision-making and problem-solving in the design and making process, it would be interesting to see further research into emotions in the context of making. Video was found especially useful in as it allows for a threefold benefit; in data collection, analysis and dissemination of research results.

The theoretical framework of embodied cognition was found relevant and informative in the analysis of sensory experiences and the making practice; consequently, it can be recommended for further investigations. Design and craft practices are still largely body-based and considerable sense-making activity takes place in embodied material manipulation, thus I propose that embodied cognition be included in the concept of design thinking.

Acknowledgements
This research is part of the Handling Mind research project, funded by the Academy of Finland (project number 266125). I would also like to pay tribute to the co-authors of previous articles that this contribution is based on: Professor Maarit Mäkelä and Professor Pirita-Seitamaa Hakkarainen, who have collaborated on and supported this research project through tutoring, editing and theoretical discussions. Many thanks also to Riitta Lahtinen of the Finnish Deafblind Association for her help and wise advice in regard to the first case study. Finally I am much obliged to all the participants of the study.

Camilla Groth
Doctoral Candidate
Aalto University, School of Arts, Design and Architecture, Department of Design.
Email address: camilla.groth@aalto.fi

References

Ahsen A. (1984). ISM: The triple code model for imagery and psychophysiology. *Journal of Mental Imagery*, 8(4), 15-42.

Akin, Ö. (1997). Descriptive models of design. *Design Studies*, 18(4), 323-326.

Akin, Ö., & Lin, C. (1995). Design protocol data and novel design decision. *Design Studies*, 16(2), 221-36.

Almevik, G., Jarefjäll, P., & Samuelsson, O. (2013). Tacit record: Augmented documentation methods to access traditional blacksmith skills. In H. Gottlieb (Ed.) *NODEM 2013 Beyond control – The collaborative museum and its challenges.* Conference Proceedings of the International Conference on Design and Digital Heritage. Stockholm, Sweden.

Anttila, P. (2006). *Tutkiva toiminta ja ilmaisu, teos, tekeminen*. (Translation: Research practice and expression, artefact, making). Akatiimi oy, Hamina.

Biggs, M. (2004). Learning from experience: Approaches to the experiential component of practice based research. In H. Karlsson (Ed.) *Forskning-Reflektion-Utveckling* (pp. 6-21). Stockholm: Swedish Research Council.

Brown, T. (2009). *Change by design: How design thinking transforms organizations and inspires innovation.* New York: Harper Collins.

Buchanan, R. (1992). Wicked problems in design thinking. *Design Issues*, 8(2), 5-21.

Cross, N. (1982). Designerly ways of knowing. *Design Studies* 3(4), 221-227.

Cross, N. (1984). Management of Design Process. In N. Cross (Ed.) *Development in design methodology* (pp. 1-7). Chichester: Wiley.

Cross, N. Christiaans, H., & Dorst, K. (1996). Analysing design activity. *Design Issues* 17(3), 49-55.

Cross, N. (2001). Design cognition: Results from protocol and other empirical studies of design activity. In C. Eastman, W. Newstatter, & M. McCracken (Eds.) *Design knowing and learning: Cognition in design education* (pp. 79-103). Oxford, UK: Elsevier.

Cross, N. (2011). *Design thinking: Understanding how designers think and work*. London: Bloomsbury Academic.

Damasio, A. (1994). *Descartes' error: Emotion, reason, and the human mind*. New York: Putnam.

Damasio, A. (1999). *The feeling of what happens: Body and emotion in the making of consciousness*. New York: Hartcourt.

Dorst, K. (1995). Analysing design activity: New directions in protocol analysis. *Design Studies* 16(2), 139-142.

Dorst, K., Dijkhuis, J. (1995). Comparing paradigms for describing design activity. *Design Studies*. 16(2), 261-274.

Dourish, P. (2001). *Where the action is: The foundation of embodied interaction*. Cambridge: MIT Press.

Ericsson, K.A., & Simon, H.A. (1993). *Protocol analysis: Verbal reports as data.* Cambridge, MA: MIT Press (Original work published in 1984).

Ellis, C., & Bochner, A. P. (2000). Autoethnography, personal narrative, reflexivity: Researcher as subject. In N.K. Denzin, & Y.S. Lincoln (Eds.), *Handbook of qualitative research* (2nd ed.) (pp. 733-768). Thousand Oaks, CA: Sage.

Fereday, J., & Muir-Cochrane, E. (2006). Demonstrating rigour using thematic analysis: A hybrid approach of inductive and deductive coding and theme development. *International Journal of Qualitative Methods*, 5(1). Article xx.

Flanagan, J. C. (1954). The critical incident technique. *Psychological Bulletin*, 51(4).

Fredriksen, B. (2011). When past and new experiences meet. *FORMakademisk Journal*, 4(1), 65-80.

Goel, V., & Pirolli, P. (1992). The structure of design problem space. *Cognitive Science*, 16(3), 395-429.

Goel, V. (1995). *Sketches of thought*, Cambridge: MIT Press.

Goldschmidt, G. (1995). The designer as a team of one. *Design Studies*. 16(2), 189-209.

Goldschmidt, G. (1997). Capturing indeterminism: Representation in the design problem space. *Design Studies*, 18(4), 441-56.

Goldschmidt, G. (2001). Visual analogy: A strategy for design reasoning and learning. In C. Eastman, M. McCracken, & W. Newstetter (Eds.), *Design, knowing and learning: Cognition in design education.* Amsterdam: Elsevier. (pp. 199-219).

Gedenryd, H. (1998). How designers work – Making sense of authentic cognitive activities [online]. (Unpublished doctoral thesis). Lund University, Sweden. Accessed 18.02.2016 https://archive.org/details/HowDesignersWork-MakingSenseOfAuthenticCognitiveActivity

Groth, C., Mäkelä, M., & Hakkarainen-Seitamaa P. (2013). Making sense. *FORMakademisk Journal*, 6,(2), 1-12.

Groth, C., Mäkelä, M., & Seitamaa-Hakkarainen, P. (2015). Tactile augmentation: A multimethod for capturing experiential knowledge. *Craft Research Journal*, 6(1), 57-81.

Groth, C. (2015). Emotions in risk-assessment and decision-making processes during craft practice. *Journal of Research Practice*, 11(2), article M5.

Groth, C., Mäkelä, M. (2016) The knowing body in material exploration. *Studies in Material Thinking,* 14, article 02.

Höök, K. (2010). Transferring qualities from horsebackriding to design. Proceedings of the 6th NordiCHI: Extending boundaries, Reykjavik, Iceland, October 16-20. New York: ACM. 226-235.

Hornecker, E. (2011). Let's get physical: The role of physicality in tangible and embodied interactions. *ACM Interactions magazine* 18(2), 19-23.

Hornecker, E., & Buur, J. (2006). Getting a grip on tangible interaction: A framework on physical space and social interaction. Proceedings of SIGCHI 2006 Conference on Human Factors in Computing Systems. April 24-27, Montreal, Canada. ACM New York, USA, 437-446.

Hummels, C., & Van Dijk, J. (2015). Seven principles to design for embodied sensemaking. Proceedings of the 9th International Conference on Tangible, Embedded and Embodied Interaction (TEI'15), Stanford, CA, 21-28.

Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2000). Visualization and sketching in design process. *Design Journal*, 3(1), 3-14.

Johansson-Sköldberg, U., Woodilla, J. & Cetinkaya, M. 2013. Design thinking: past, present and possible futures. *Creativity and innovation management*, 22(2), 221-146.

Johnson, M. (1987). *The body in the mind*. Chicago: Chicago University Press.

Johnson, M. (2007). *The meaning of the body*. Chicago: Chicago University Press.

Kangas, K. (2014). *The artificial project: Promoting design learning in the elementary classroom*. Unigrafia, Helsinki.

Karana, E., Pedgley, O., & Rognoli, V. (2015). On materials experience. *Design Issues*, 31(3), 16-27.

Keller, C., & Keller, J. (1996). *Cognition and tool use. The blacksmith at work*. Cambridge: Cambridge University Press.

Kiefer, M., & Trumpp, M. N. (2012). Embodiment theory and education: The foundations of cognition in perception and action. *Trends in Neuroscience and Education*, 1, 15-20.

Kimbell, L. (2011). Rethinking design thinking: Part 1. *Design and Culture*, 3(3), 285-306.

Kosslyn, S. M. (2005). Mental images and the brain. *Cognitive Neuropsychology*, 22 (3/4), 333-347.

Laamanen, T-K. (2016). *Generating and transforming representations in design ideation*. Doctoral thesis. Unigrafia, Helsinki.

Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh: The embodied mind and its challenge to Western thought*. New York: Basic Books.

Muukkonen, H., Hakkarainen, K., Inkinen, M., Lonka, K., & Salmela-Aro, K. (2008). CASS-methods and tools for investigating higher education knowledge practices. In G. Kanselaar, V. Jonker, P. Kirschner, & F. Prins (Eds.), *International Perspectives in the Learning Sciences: Cre8ing a Learning World, Proceedings of the Eight International Conference for the Learning Sciences* (ICLS 2008). Utrecht, The

Netherlands, 2, 107-114.

Merleau-Ponty, M. (1962/2010). *Phenomenology of perception*. London: Routledge.

Mäkelä, M. (2007). Knowing through making: The role of the artefact in practice-led research. *Knowledge, Technology & Policy*, 20(3), 157-163.

Niedderer, K. (2007). Mapping the meaning of knowledge in design research. *Design Research Quarterly*, 2(2). 1-13.

Niedderer, K., & Townsend, K. (2014). Designing craft research: Joining emotion and knowledge. *The Design Journal*, 17(4), 624-684.

Nilsson, F. (2013). Knowledge in the making: on production and communication of knowledge in the material practices of architecture. *FORMakademisk*, 6(2), 1-13.

Nimkulrat, N. (2009). *Paperness: Expressive material in textile art from an artist's viewpoint*. Helsinki, Finland: University of Art and Design Helsinki.

Nimkulrat, N. (2012). Hands-on intellect: Integrating craft practice into design research. *International Journal of Design*, 6(3), 1-14.

Noë, A. (2004). *Action in perception*. Cambridge: The MIT Press.

Noë, A. (2009). *Out of our heads*. New York: Hill and Wang.

O'Connor, E. (2005). Embodied knowledge: The experience of meaning and the struggle towards proficiency in glassblowing. *Ethnography*, 6(2), 183-204.

O'Connor, E. (2007). Hot Glass: The calorific imagination of practice in glassblowing. In C. Calhoun and R. Sennett (Eds.), *Practicing culture*. London: Routledge. pp. 57-81

Ojala, M. (2013). Constructing knowledge through perceptual processes in making craft-art. *Techne A Series*, 20(3), 62-75.

Pink, S. (2009). *Doing sensory ethnography*. London: SAGE Publications.

Pink, P. (2011). A multisensory approach to visual methods. In E. Margolis, & L. Pauwels (Eds.), *The SAGE handbook visual research methods* (pp. 601-615). London: SAGE Publications.

Pink, S., & Leder Mackley, K. (2012). Video and a sense of the invisible: Approaching domestic energy consumption through the sensory home. *Sociological Research Online*, 17(1), 3. Retrieved from http://www.socresonline.org.uk/17/1/3.html on 24/9 2015.

Polanyi, M. (1958). *Personal knowledge*. London: Routledge & Kegan Paul.

Poulsen, S., & Thøgersen, U. (2011). Embodied design thinking: A phenomenological perspective. *CoDesign: International Journal of CoCreation in Design and the Arts*, 7(1), 29-44.

Purcell, A.T., & Gero, J.S. (1998). Drawings and the design process. *Design Studies*, 19(1), 389−430.

Ramduny-Ellis, D., Dix, A., Evans, M., Hare, J., & Gill, S. (2010). Physicality in design: An exploration. *The Design Journal*, 13(1), 48-76.

Rittel, H.W., & Weber M.M. (1984). Planning problems are wicked problems. In N. Cross (Ed.), *Development in design methodology* (pp. 136-144). Chichester: Wiley.

Rompay, T., Hekkert, P., & Muller, W. (2005). The bodily basis of product experience. *Design Studies*. 26(4), 359-377.

Rompay, T., & Ludden, G. (2013). Embodiment in design: On the embodied foundations of meaning and experience in product design. *Conference proceeding at the 5th IASDR 2013 Tokyo Conference.* Tokyo, Japan.

Rowe, P.G. (1987). *Design thinking*, Cambridge: The MIT Press.

Puntambekar, S., & Hubscher, R. (2005). Tools for scaffolding students in a complex learning environment: What have we gained and what have we missed? *Educational Psychologist*, 40(1), 1-12.

Schön, D. (1983). *The reflective practitioner: How professionals think in action*. New York: Basic Books.

Seitamaa-Hakkarainen, P., Huotilainen, M., Mäkelä, M., Groth, C., & Hakkarainen, K. (2016). How can neuroscience help to understand design and craft activity? The promise of cognitive neuroscience in design studies. *FORMakademisk, 9 (1).*

Tin, M.B. (2013). Making and the sense it makes. Conceptual manifesto simultaneously published in *FORMakademisk*, 6(2); *Studies in Material Thinking*, 9, and *TechneA Series*, 20(3), 1-4.

Trotto, A., & Hummels, C.C.M. (2013). Designing in skills: Nurturing personal engagement in design. In Proceedings of the *5th International Congress of International Association of Societies of Design Research (IASDR).*

Varela, F.J., Thompson, E., & Rosch, E. (1991). *The embodied mind: Cognitive science and human experience.* Cambridge: The MIT Press.

Wilde, D., Tomico, O., Lucero, A., Höök, K., & Buur, J. (2015). Embodying embodied design research techniques. In *Critical Alternatives: Workshops and Demos: Proceedings of The Fifth Decennial Aarhus Conference 17- 21 August 2015, Aarhus, Denmark.* (Vol. II,). Aarhus Series on Human Centered Computing, 1(1), 39-42.

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology & Psychiatry & Allied Disciplines*, 17(2), 89-100.

Yin, R. K. (2009). *Case study research: Design and methods*. Thousand Oaks: SAGE Publications.

Zuo, H., Hope, T., Castle, P., & Jones, M. (2001). An Investigation into the sensory properties of materials. In the proceedings of *The 2nd International Conference on Affective Human Factors Design.* London: Asean Academic Press.

http://dx.doi.org/10.7577/formakademisk.1480

Tellervo Härkki, Pirita Seitamaa-Hakkarainen and Kai Hakkarainen

Material knowledge in collaborative designing and making

A case of wearable sea creatures

Abstract

This article is based on a study of novice designers' knowledge of materials in a challenging collaborative assignment. We approached material knowledge from two complementary viewpoints: the dimensions of knowledge shared during designing, and how student teams built new knowledge during making. We found that both modalities studied—namely, words and gestures—contributed to advancement in designing. The modalities became specialised: While words served mainly to identify materials and to describe visual qualities, gestures conveyed information about size, shape, location and dynamic dimensions, such as movement and change over time, as well as signature qualities based on embodied experience. During making, ambitious teams took material decisions and the challenge of authenticity seriously, but the tight timeframe and budget compelled them to favour pragmatic choices.

Keywords: collaboration, designing, gestures, embodied experience, making, material knowledge

Introduction

In the present study, we engaged undergraduate student teams in a challenging collaborative designing and making assignment, and we studied the material knowledge that the students manifested while translating from one format to another: namely how the teams wove materials into conversations in the early stages of designing, how they made decisions regarding how to materialise their ideas, and how they utilised material explorations to gain a deeper understanding of materials as they produced a materialisation of the aspired-to user experience. The assignment took first-year textile teacher students to meet a client, SEA LIFE Helsinki (http://www.visitsealife.com/helsinki), a public aquarium. The client requested custom-made accessories—wearable sea creatures—for groups of visiting day care children to use. The basic material challenge—creating a three-dimensional (3D) form and the desired user experience with a limited budget and timeframe—became even more challenging under the following premises: The final product must make maximum use of recycled materials and be authentic, easy to dress and easy to maintain. With this setup, we encouraged novice students to innovate, play, explore and stretch the limits of their knowledge of formgiving and materials, with a taste of a longer one-term collaborative team assignment.

The materialisation of conceptual ideas and formgiving relies on *material knowledge*. The richer the knowledge of materials, the more solutions a designer can see and express (Alesina & Lupton, 2010, p. 4). However, material knowledge has several dimensions. From the viewpoint of a designed object, materials not only provide technical functionality but also create the personality of an artefact (Ashby & Johnson, 2014, p. 5). Doordan (2003) introduced three perspectives on materials: fabrication, application and appreciation by users. With an emphasis on the user experience, Karana, Pedgley and Rognoli (2015) identified four components of a designer's material knowledge: (1) experiential aspects, such as aesthetics, meanings and emotions; (2) the effects of design features, such as form, process and finishing; (3) user characteristics, such as gender, age and culture; and (4) the context in which the artefact will be used. Ramduny-Ellis et al. (2010) noticed that a designer's past knowledge and skills suggest how materials can be used.

Some material knowledge can be more general in nature, such as knowledge of the selection of currently available materials, their technical properties, their sustainability and experiential qualities, and ways of processing the required materials and tools. This kind of knowledge can be acquired partly from books or from more advanced colleagues, but one can acquire a deeper understanding only through a personal, embodied experience. That deeper understanding has a more relational and dynamic nature than static propositional knowledge does, and it is bounded by the accompanying task, grounded in and structured by various patterns emerging throughout the sensorimotor activity as we manipulate objects, orient spatially and temporally, and direct our perceptual focus (Gibbs, 1997, p. 354). This kind of material knowledge guides the selection of materials to create an aspired user experience, restrained by a given budget, timeframe and skills; informs to combine certain materials to achieve well-behaving structures; and suggests the techniques, tools and supplementary materials needed to achieve the aspired form and function. The latter kind of material knowledge in particular has features of *working knowledge* (Baird, 2004): Knowledge acquisition has a tool-like nature, that is, acquiring knowledge enables the effective application and further extension of that knowledge, and it yields aspired-to accomplishments. In the present study, we approach designers' material knowledge as a tool they use for designing and making.

A collaborative setup brings an additional challenge—and an additional source of inspiration, for that matter: a team. We use *collaboration* to refer to a process in which students actively work together in creating and sharing their ideas, deliberately making joint decisions and producing shared design objects, constructing and modifying their solutions, and evaluating their outcomes through discourse (Hennessy & Murphy, 1999). Moreover, successful collaboration requires the building of knowledge and the utilisation of that knowledge productively, taking into account other teams members' interests and strengths. It requires the sharing of one's knowledge, ideas and embodied experiences, as well as the evaluation, adoption and adaption of knowledge, ideas and embodied experiences that others share, either in conversations or in interactions with materials. These shared expressions are multimodal in nature, involving speech, hand gestures, movements of the head and eyes, changes in bodily postures, and, for instance, creating and utilising two-dimensional (2D) or 3D models and engaging artefacts. When communication involves several modalities, they all contribute to conveying meaning, but their roles vary: Each of the participating modalities carries different aspects of these expressions in different ways by interacting with and contributing to the other modalities (Jewitt, 2014, p. 27). *Modal affordance* by Kress (1993) refers to what one can express and represent easily with each modality; the previous use of the modality and the social conventions related to it shape this affordance. Thus, in this way, modalities have become specialised, developing different capabilities for a particular task (Jewitt, 2014, p. 26). Furthermore, modalities not only supplement one another but also interpenetrate one another (Streeck & Kallmayer, 2001). Gesture and speech can be considered two different kinds of expressive resources, partners in the construction of the final expression (Kendon, 2004, p. 111).

Creative collaborative efforts to build knowledge and to design artefacts are often associated with the adaption of new *vocabulary*: Proper nouns replace common nouns, and more accurate terms and professional terms replace vague and descriptive expressions (Kangas, Seitamaa-Hakkarainen, & Hakkarainen, 2013); vocabulary grows with the adoption of more specific expressions. Yet, in design conversation, the words one uses reveal many things, not just the level of material knowledge: the level of detail with which the team is working (that is, a measure of progress); if the planned features are easily translated into material form (i.e. shiny vs. fearsome); if the aspired-to expression is tacit or lexical in nature. The selected expressions could even be a part of the negotiation tactics or indicate the level of agreement that the team members have reached (or failed to reach). In design, decisions are made, and immature details—whether from the viewpoints of design premises, (material) knowledge or group processes—remain open; meanwhile, working hypotheses are established and worked with. The process requires both general and specific expressions.

According to Pedgley (2014, p. 340), 'the fundamental building block' when creating a user experience is *sensorial information*, that is, the *designer's embodied experience* of the sensory qualities of materials, which are not always easy to express in words. Furthermore, the aspired-to user experience needs to be created in 3D form. That 3D form is grounded in various material decisions of a spatial nature: size, shape and location in the use-space (i.e. the physical and social environment where the final artefact will be situated and used). Of the modalities noted above, *gestures* play an acknowledged role in spatial cognition: in expressing, communicating and thinking about spatial information (for an overview, cf. Alibali, 2005). Some people gesture more than others, but gesturing also appears to be task dependent: Spatial task content increases gesturing. Lavergne and Kimura (1987) noticed that people produced twice as many gestures when talking about spatial topics than when talking about verbal or neutral topics. In addition, Melinger and Levelt (2004) found that speakers producing iconic gestures (that is, gestures presenting images of concrete entities or actions (McNeill, 1985)) representing spatial relations omitted more spatial information from their speech than speakers who did not gesture. The modalities were specialised according to the task. In designing, gestures have been found to offer specific possibilities for expressing spatial and motion-related qualities (Visser, 2010). To sum up, our starting point in the present study is that in a collaborative design conversation, *gestures carry embodied (material) experiences not necessarily expressed in words*.

Based on these premises, we set out to study *material knowledge shared within the novice student teams:* (1) *their use of words and gestures* in expressing material knowledge during design conversation, and (2) *how they build material knowledge* via material decisions and explorations in the making phase.

Setting: Designing and making wearable sea creatures

Structure and approach of the assignment

The present study employed some of the data gathered for a longer research project on collaborative design (for earlier results, see Lahti et al., 2016). This time our collaborative designing and making assignment stretched over three compulsory first-semester courses in textile teacher education at the University of Helsinki, Finland. The design phase was included in the Basics of Craft and Design Studies course, the first to engage students in designing. The making phase took place mainly in a Sewing Technology course. In addition, the teams could freely decide whether they wanted to produce parts of their accessories during a Knitting and Crocheting course.

To facilitate novice teams' designing and making endeavours, we created *a supporting structure*: a sequence of clearly framed steps. Within that structure, teams engaged with the authentic environment and followed expert guidance about the world of sea creatures; tasks focusing their attention on aspects of design (identifying and agreeing on the premises, formgiving in 2D and 3D, visual and haptic experiences in collage format); client feedback on design outcomes; and organizing teamwork for the making phase. The support mechanism for the making phase emphasised *material explorations*, that is, testing in practice whether the planned structures and features could be implemented successfully, and what materials worked best.

The support structure, on the one hand, assured that the novice teams focused their attention on pertinent aspects of designing and making, but, on the other hand, granted the teams a degree of autonomy to innovate and prioritise the given premises. The support structure, as well as designing and making assignments in general, can be considered a manifestation of the *design mode,* where knowledge and ideas are approached as objects of creation and advancement, extension and application rather than as objects with a given truth value (which is characteristic of belief mode, typical of traditional educational activities) (Bereiter & Scardamalia, 2003). In design mode, the pivotal concern is the usefulness, improvability and developmental potential of ideas in relation to the design challenge at hand (Bereiter & Scardamalia, 2003).

Practical arrangements for data gathering: videos, eDiaries and team interviews

For the research project, we selected 12 volunteer participants from all 38 students attending the courses. The selection was based on their willingness to volunteer and their ability to participate in a sewing technology course in which the designs were completed. The students were divided into four teams of three participants each. The participants ranged in age from 21 to 45 years, and none held a university-level degree in design or textile craft.

While designing, the teams worked in different rooms. We video recorded three sessions (constructing design premises, 2D visualisation and 3D modelling) and collected all the design documents that the teams produced. Unfortunately, video recording proved impossible during the making phase due to student teams' need to use various working spaces (e.g. material storages in different classrooms, cutting tables, ironing stations) and the noisy overlock as well as other sewing machines. Consequently, the data collection took the form of a structured web-based *eDiary.* For each material decision or exploration, the teams wrote an eDiary entry and attached one to three photos. Questions in the eDiary focused on the objectives of the experiment, the materials and tools used, the selection criteria, observations and planned next steps.

Furthermore, we interviewed the teams after the making phase. These semi-structured interviews (Cohen, Manion, & Morrison, 2007) were based on the teams' eDiary entries and served to enrich the descriptions in eDiary.

For practical reasons, in the present study we were unable to analyse all the video materials from the design phase, but instead focused on the most promising part of the data. We initially intended to analyse the materials from the 3D modelling session; along with the task of building a mock-up, we specifically reminded the students to focus on the actual materials. The students behaved differently than the teachers expected, however. Preliminary viewings of the video recordings revealed that the 2D visualisation session was the richest in material ideas; thus, the visualisation session became our data source for the design phase. The making phase had no such distractions. Table 1 shows the two data sets used.

Table 1. Data corpus for the present study.

Phase and session	**Collected data**	**Amount of data**				
		Team 1	**Team 2**	**Team 3**	**Team 4**	**Totals**
Design: Visualisation	Video footage (minutes)	88	40	72	27	227
Making phase	eDiary entries (pcs)	12	9	13	8	42
End: Team interviews	Video footage (minutes)	36	34	38	25	133

Analysis methods for shared material knowledge

In the present study, we used two data sets: video recordings of 2D visualisation sessions and eDiaries along with team interviews describing material decisions and material explorations. The analysis methods we used for each data set appear in Figure 1.

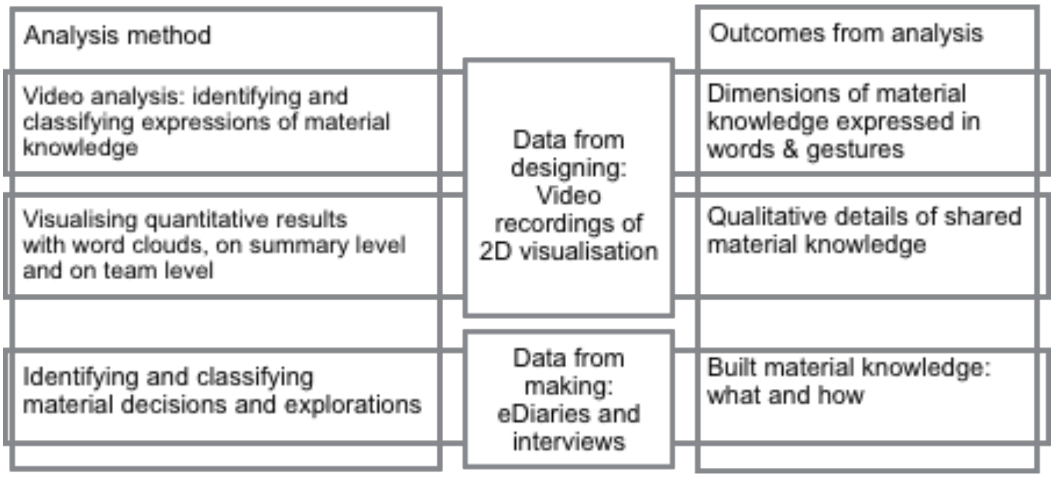


Figure 1. Analysis methods, target data and outcomes.

In this section, we describe the methods we used to study *material knowledge shared within the novice student teams.* We started with identifying and classifying expressions of material knowledge in design conversations to see teams' *use of words and gestures to express shared material knowledge*, as well as to uncover *qualitative details.* Additionally, we describe the methods we used to identify *the material knowledge the teams built and how they did it* in the making phase.

Analysing the teams' expressions of material knowledge while designing

Our first step was to identify and transcribe expressions of shared material knowledge from the video recordings. The expressions, on the one hand, pinpointed certain materials by *naming* them (e.g. 'cotton', 'Velcro'), and, on the other hand, by *describing their qualities* (e.g., 'leathery', 'transparent', 'thorn-like'). Even though the above approach seemed straightforward, we experienced certain challenges. Form and structure were central topics, and to discuss them, the teams used common nouns such as 'fabric' to refer to a certain part of the structure (e.g. 'fabric' meaning 'bottom layer' instead of referring to a cloth-like material). To maintain the focus on expressions of materiality, we omitted from the analysis words that the teams clearly used to refer to structural parts instead of the materials.

After identifying the expressions in words, we moved on to gestures. Analytically, gestures are 'units of visible bodily action identified by kinesic features which correspond to meaningful units of action such as pointing, a depiction, a pantomime or the enactment of a conventionalised gesture' (Kendon, 2004, p. 108). *Conventionalised gestures*, also known as emblems (Ekman & Friesen, 1969) or symbolic gestures (Wundt, 1973, p. 88), are gestures with a specific normative meaning within a specific community; they have a direct verbal translation. For instance, hand gestures such as the 'OK' sign and 'V' for victory are conventionalised gestures well recognised in the West. However, when interpreting other than conventionalised gestures, the context is of critical importance. The key to interpreting is the sequential structure of human interaction. Four sources of meanings need to be considered: (1) co-occurring speech, (2) a prior stimulus or a cause that provoked the gesture to occur (e.g. previous turn-at-talk or action), (3) a subsequent response to, or an effect of the gesture (e.g. turn-at-talk responding to the gesture), and (4) the purely kinesic characteristics of the gesture (Enfield, 2009, p. 9).

Kendon's continuum (McNeill, 1992, pp. 37–40) recognises two kinds of gestures where speech is present at some level: gesticulation and language-like gestures; the latter are also known as speech-framed gestures (McNeill, 2006, p. 59). *Gesticulation* refers to a motion that embodies a meaning relatable to accompanying speech, whereas *speech-framed gesture* refers to a gesture that completes a sentence structure by occupying a slot in the sentence. From this point onward, we refer to both gesticulation and speech-framed gestures as *gestures*. To identify gestures that (potentially) carry expressions of material knowledge, we focused on *substantial gestures*, that is, gestures that contribute to the content of co-speech (Kendon, 2004). In practice, we reviewed the video recordings several times and looked for substantial gestures that accompany the previously identified expressions in words, or that occupy the place of a word and convey a material attribute.

After identifying all the expressions of shared material knowledge, we needed a classification scheme to separate various dimensions of material knowledge. Several studies have examined gestures in the context of face-to-face collaboration in designing (e.g. Donovan, Heineman, Matthews, & Buur, 2011; Eris, Martelaro, & Badke-Schaub, 2014; Tang, 1991), emphasising aspects specific to designing artefacts (e.g., Bekker, Olson, & Olson, 1995; Détienne & Visser, 2006; Murphy, 2010; Visser, 2010). To our knowledge, however, no classification scheme for substantial gestures has focused on their expressional power regarding designing or on the (material) knowledge needed in designing. We therefore chose to use the same classification scheme for both gestural expressions and expressions in words. We based our classification on a study of architectural students' visual and tactile assessments of building materials (Wastiels et al., 2013), which identified the following seven dimensions: (1) naming the material; (2) technical properties; (3) sensory aspects; (4) typical use of the material; (5) expressive meanings, that is, values and personality characteristics attributed to the material; (6) associative meanings, that is, associations requiring retrieval from memory and past experiences; and (7) emotions evoked by the materials. Due to differences in research settings and to our broader focus—not just words but words and gestures as well—we fine-tuned the scheme. Table 2 shows the adapted classification scheme.

Table 2. Classification of expressions of material knowledge through words or gestures.

Dimensions		**Description**
1	Naming	Name of a material; name of an object; name of a technique; an object is identified by gestures mimicking its signature qualities; a technique is identified through mimicking gestures; or a material is identified with a pointing gesture
2.	Behaviour of material	How the material behaves in a proposed solution, or one of its technical qualities
3.	Sensory	
3.1	Sensory-visual	Aspects sensed visually
3.2	Sensory-tactile	Aspects sensed tactually
3.3	Sensory-spatial	Spatial qualities, such as form, size and location
4.	Expressive meanings	Meanings related to concepts and phrases
5.	Associative meanings	Meanings related to other objects
6.	Valuations	Personal valuations attributed to the material or to materiality

In our data, 'naming' also occurred by referring to objects (e.g. 'we could use a non-slip bathtub mat') and techniques (e.g. 'like crocheted') or by gestures (e.g. by pointing). Our class of 'behaviour of material' includes both original categories of 'technical qualities' and 'behavioural qualities', as behaviours were usually derivatives of technical properties. Instead of holding just one class, 'sensory', we divided it into two parts—'sensory-visual' and 'sensory-tactile'—to understand more clearly the types of experiential knowledge expressed. A third part, 'sensory-spatial', accounted for the strengths of gestural expressions. Our teams made 'valuations' rather than expressed 'emotions', and no statements described the 'typical use of the materials'.

In the analysis, we treated the classes as mutually exclusive. For the purposes of classification, we applied the model from Enfield (2009, p. 15), in which the meaning of a communicative move (e.g. an expression) is derived from two main sources: a conventional (normative) component that is based on the lexicon or grammatical role, and a non-conventional component that is based on the context, either explicit or implicit. In our data, for expressions in words (i.e. vocal expressions), the conventional component (lexical meaning) was—in most cases—available and plausible, which left less room for interpretation. On the contrary, for gestures, community-wide normative meanings were unavailable, which left visual impressions based on kinesic features in the context as the only sources for deriving meanings. Consequently, the context of the conversation was important. The word 'dyed', for instance, could refer to a *specific dyed material* discussed previously, or to a *quality* that could convey the aspired impression. In the first case, we classified 'dyed' as 'naming' and in the second case as 'sensory-visual'. The environment, INTERACT software, and our way of carrying out the video analysis appear in Figure 2. For each expression in words, we transcribed the vocal part, usually one or two words, and, if deemed necessary for the purposes of the interpretation of meaning, we also transcribed the turn-at-talk(s) and other relevant actions before and after the expression in question. For each gesture, we wrote an annotation to describe the kinesic features and transcribed the accompanying speech, or, if there were none, we transcribed turns-at-talk and other relevant actions before and after the gesture in question. With the help of those annotations and transcripts and the video footage running, we interpreted the meanings that the gestures conveyed. The researcher's intuition—in addition to familiarity with the context—was a highly important tool.

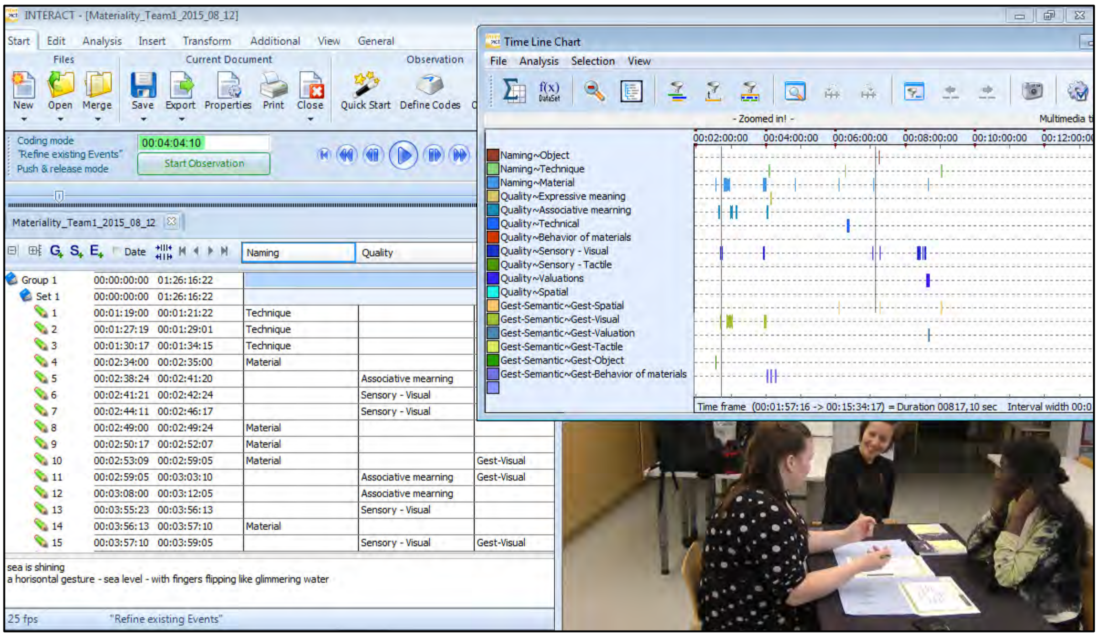


Figure 2. Using INTERACT software for the video analysis.

To visualise the classified data, we exported the transcribed expressions in words from INTERACT and created word clouds with the Wordle.net service. In a word cloud, the size of a word depicts the frequency of its appearance in the data; word clouds are graphical illustrations of frequency counts. In our analysis, a word cloud implies the kind of material knowledge the teams frequently shared. Fewer but larger words suggest a conversation of a cumulative nature: material ideas were fewer, but those ideas were referred to several times. The opposite, a large number of small words, suggest that the design conversation had a divergent nature: Several material ideas were proposed. We created word clouds for each dimension, on both a summary level, to include data from all the teams, and a team level.

Analysing the building of material knowledge via material decisions and explorations

In the making phase, the teams implemented designed features in a material form. Teams decided on the materials and, whenever necessary, tested whether they could successfully implement the planned features or structures and identified which materials worked best. The teams shared, accessed, adopted, adapted and built material knowledge in the process. First, we segmented eDiary and team interview data. Usually, an eDiary entry described one material decision or one exploration, but some entries mentioned two or even three. During the stimulated recall interviews, the teams supplemented their written entries and sometimes brought up previously unreported decisions. For the purposes of analysis, we entered each reported decision and exploration into an Excel spreadsheet as a separate entry. All in all, the frequencies of explorations for Team 1 were 19; Team 2, 20; Team 3, 23; and Team 4, 18.

To understand the dimensions of material knowledge with which the teams were struggling, we classified material decisions and explorations according to their objectives: (1) to *select a material; (2*) to get a deeper understanding of *a processing technique; (3)* to adjust *tools* or to practice their use; and *(4)* to test whether the planned *combination of materials*, that is, the structural idea worked—in short, a data-driven classification scheme. Next, we analysed *how* the teams built knowledge, including their approaches, decision criteria and success rates. Bohnenberger (2013, p. 191) identified three approaches to exploring the properties and behaviour of materials: theoretical, virtual and physical encounters. In our data, we used only the first and last approaches. Bohnenberger's theoretical encounters parallel situations in which a team did not actually handle the material(s) but instead *made a decision based on their working knowledge.* We divided physical encounters (Bohnenberger, 2013, p. 191) into two to emphasise the differences between the teams' working practices, specifically, whether a team chose a material *based on sensory perception* (its visual and tactile qualities), or *based on material manipulation*, that is, testing how the material behaved as part of the design. Additionally, we used data-driven classes to analyse *the criteria that the teams used to evaluate whether to make the decision*. The classes were as follows: (1) The team considered that the solution fulfilled the premises, that is, it was *fit for purpose*; (2) the solution was *easily available and fitting enough*; and (3) the solution was *a compromise due to schedule, budget or skills*. Finally, we used data-driven classes to analyse *consequences*, that is, if (1) the first-proposed solution passed; or in case the first-proposed solution did not pass, (2) the team created a new solution to fulfil the planned feature; or (3) the team reprioritised the design premises to find a solution. The last two measures—criteria and consequences—imply how persistently the teams searched suitable material solutions.

Findings on material knowledge shared within the novice student teams

This section begins with a description of how the teams expressed their material knowledge through words and gestures, and it ends with describing how the teams built material knowledge during the making phase.

Shared material knowledge expressed in words and gestures

We identified a total of 612 expressions in words and 180 gestural expressions. Table 3 presents the dimensions of material knowledge in total and at the team level. Starting with the totals, the most common dimension of material knowledge shared was 'naming', that is, identifying the material to be used. The qualities of 'sensory' and 'behaviour of material' frequently supported identification. Comparing the two modalities showed that words favoured 'naming' and gestures 'sensory' qualities. The specialisation of modalities was obvious.

Table 3. Expressions of material knowledge at the team level and in total.
W= Expressions in words, G= Gestural expressions

Classification	Team 1		Team 2		Team 3		Team 4		All teams		All Expressions (%)
	W (%)	G (%)	W (%)	G (%)	W (%)	G (%)	W (%)	G (%)	W (%)	G (%)	
Naming	44	10	54	8	55	30	47	35	50	22	43
Sensory	24	58	16	50	23	53	30	47	24	52	31
Behaviour of material	17	25	25	38	17	18	17	16	18	22	19
Valuations	5	7	5	4	3	0	3	2	4	3	4
Expressive & associative	9	0	0	0	2	0	3	0	4	0	3
Totals	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Overall, comparing expressions in words in total and at the team level reveals the same tendency: '*naming' was the first, 'sensory' the second and 'behaviour of material' the third in volumes*. One exception was Team 2. Prior to the visualisation session, they had already boldly chosen leather as their main material—a material not included in the curriculum but well suited to the challenge of creating authentic sea creatures—and techniques unfamiliar to them: painting and moulding leather. Therefore, at this point they had fewer material details to evaluate and decisions to make than did the other teams.

Data on gestures revealed both similarities and differences between the teams, not only in the frequency of gestures in general but also in their dimensions. While *the majority of gestures implied 'sensory' dimensions* for all of the teams, the second place was divided between 'behaviour of material' (teams 1 and 2) and 'naming' (teams 3 and 4). Watching the videos showed that, instead of using hand gestures to express valuations, the teams used nods and facial gestures, which were beyond the scope of this study.

The videos revealed that some repetition had taken place, that is, not all expressions in words were unique. To understand the qualitative nature of the expressions more deeply, another analysis was carried out with the help of word clouds. For reasons of space, the only word clouds represented are at the level of all of the teams, but the text also describes the results on the team level. This analysis is presented for the three most popular dimensions: 'naming', 'sensory', and 'behaviour of materials'.

The 'naming' dimension in detail

The word cloud 'naming' (Figure 3) shows the materials in which (all of) the teams invested. Combining the information in the word cloud with observations from the videos, we concluded that the teams' tendency to use 'fabric' as a general-level expression partly explained the high frequency (in the cloud, the large size) of the word 'fabric'; a common meaning of the word 'fabric' was '*unidentified textile material*'. A general expression, such as 'fabric', 'rib', 'yarn' and 'veil', usually served as the *starting point for more detailed* *planning*. Rather than a narrow vocabulary, that implies that the designing of material features began with general-level material ideas.

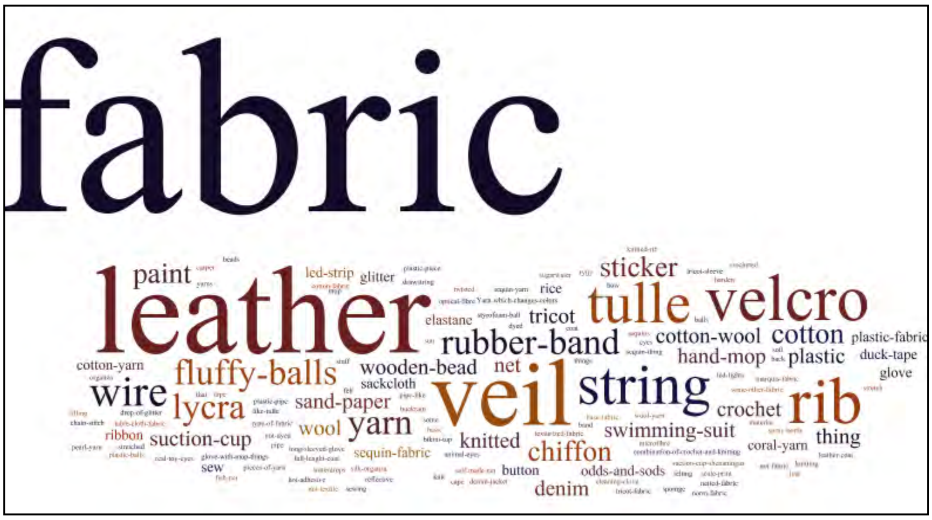


Figure 3. Word cloud visualising shared material knowledge in the 'naming' dimension.

Team-level clouds revealed that *each team had their own key material questions* around which they delved: Team 1 moved between 'net' and 'fabric' to create a visual impression of sea and waves with shiny 'glitter', 'sequins' and 'beads'; Team 2 used 'leather' as their main material and questioned what kind of 'rib' they should use for the fastenings; Team 3 speculated whether the 'fabric' for creating a 3D octopus form, with as few seams as possible, could be 'swimming suits', and whether a 'veil' made of 'tulle' would move like octopus ink; and Team 4 played with the idea of using non-traditional, non-textile materials, such as 'fluffy balls' and 'hand mops', for corals, and they decided to use 'string' instead of 'Velcro' for fastening their cape.

The 'sensory' dimension in detail

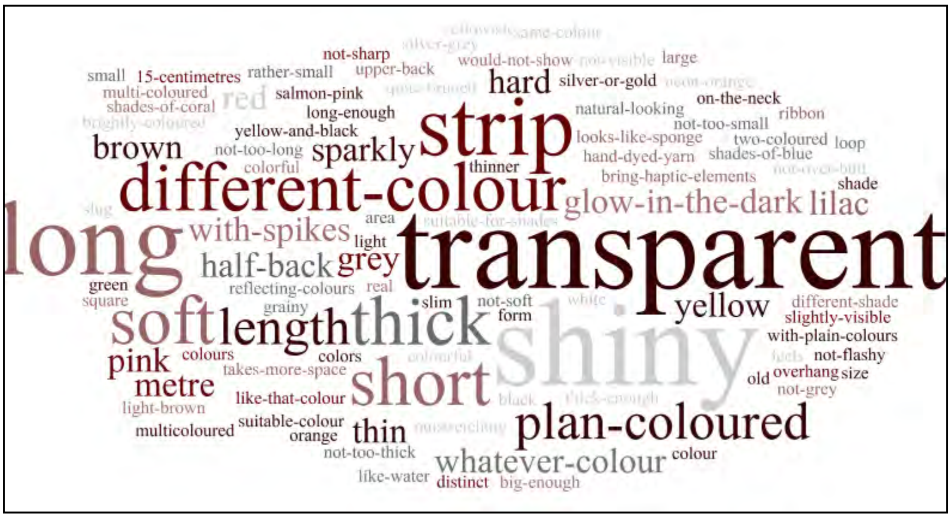


Figure 4. Word cloud visualising shared material knowledge in the 'sensory' dimension.

The word cloud 'sensory' (Figure 4) holds more high-frequency words (that is, words with a larger size) than does the previous cloud 'naming'; sensory expressions for aspired-to material qualities seemed to accumulate more evenly than did the names of the materials. In other words, evaluating and negotiating a specific sensory quality was common, whereas the teams had sufficient material knowledge to identify several candidate materials that held the aspired-to quality. Of course, this is with the exception of Team 2, which had committed themselves to moulding and painting leather—a material they considered to offer the most authentic user experience. *All in all, the teams considered sensory qualities to be important mediators in the creation of the user experience.*

The quantitative results in Table 4 below sharpen the impressions based on the word cloud 'sensory'. *In words, 'visual' expressions*—the presence or lack of colours—*dominated*. One exception was Team 4, which preferred 'spatial' expressions to 'visual'; they discussed more about size and measures than did the other teams, even though the measures in question were not particularly complicated. In general, 'tactile' expressions remained few, even though the assignment instructions emphasised that aspect. For all teams, gestures showed their strength in expressing 'spatial' qualities.

Table 4. Expressions of materiality: subclasses of 'sensory'.
W=Expressions in words; G=Gestural expressions

	Team 1		**Team 2**		**Team 3**		**Team 4**	
Classification	**W (%)**	**G (%)**	**W (%)**	**G (%)**	**W (%)**	**G (%)**	**W (%)**	**G (%)**
Sensory-visual	81	26	61	8	65	5	25	4
Sensory-tactile	5	6	6	8	3	19	21	15
Sensory-spatial	14	68	33	83	32	76	54	81
Sensory total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Often in the conversations, gestures played an elemental role in conveying aspects of aspired-to features or material ideas. When comparing spatial expressions in words—such as 'long', 'thick' and 'strip'—with gestural expressions, the latter conveyed *richer content* in economic form. For instance, a gesture accompanying a suggestion that fabric representing octopus ink could be 'strips' (see Figure 5 on the next page) included information about length, width and the curly nature of the strips, as well as the way the strips would hover freely, all of which suggests that the material should be something that is light and that moves easily. Without that gesture, a much longer description would be necessary; otherwise, meanings would be lost.

Sometimes, *gestures express meanings that persons with the same material experiences intuitively understand* (LeBaron, & Streeck, 2000), which enables *the fast transmission of ideas* and *the communication of embodied experiences*. The following transcript introduces fluffy balls, meaning spikey plastic toy balls. It should be noted that the words 'fluffy balls' cannot be found in any lexicon; the phrase has no normative community-wide meaning. Two of the students (Laney and Cora) had the same material experience of fluffy balls, while the third one (Ruby) did not, or, at least, her experience was much feebler. The transcribed episode shows how Laney's gestures conveyed the signature qualities of 'fluffy balls'—which Cora immediately recognised, based on her own embodied experience of the balls—and how long it took for Ruby to figure out what the others meant by 'fluffy balls'. A detailed analysis of the episode follows the gestures in Figure 6 and the transcript text in Table 5.

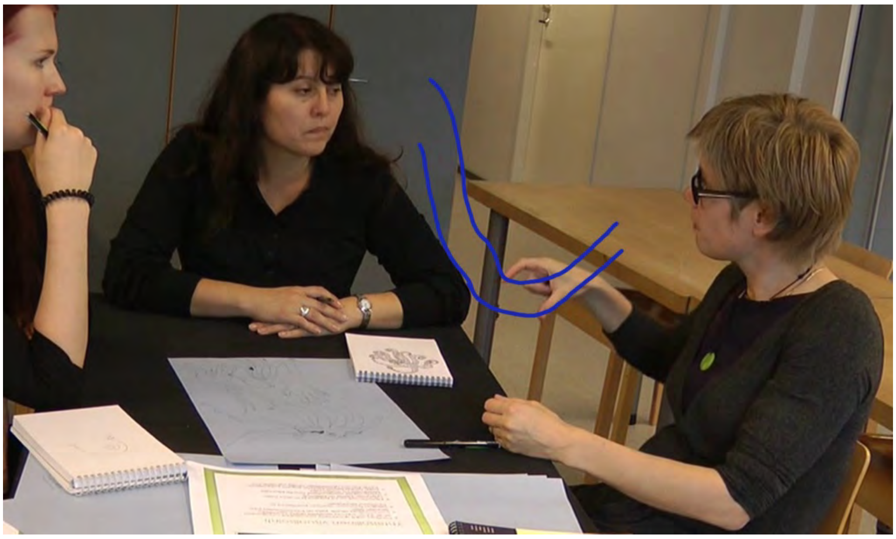


Figure 5. Team 3, a proposal of a strip representing octopus ink, 0:14:13–0:14:16.

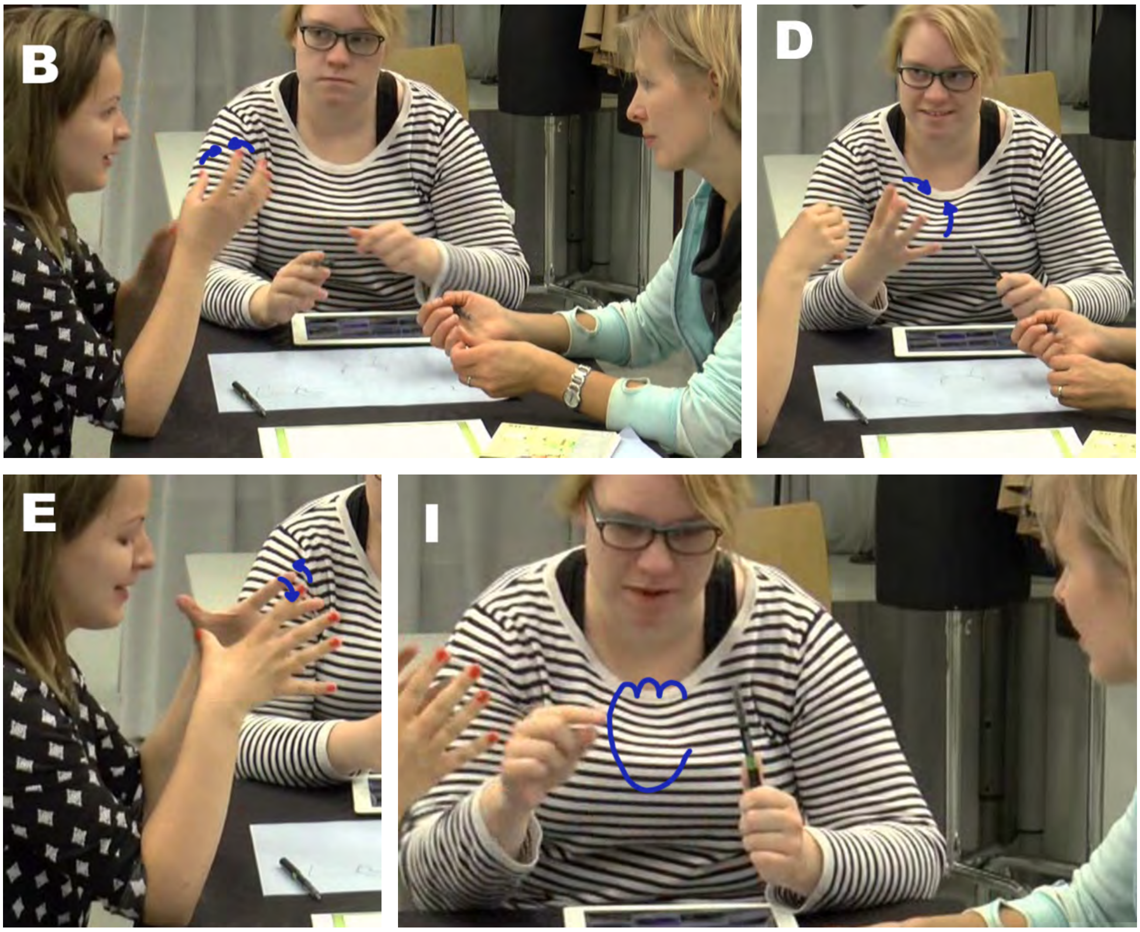


Figure 6. Gestures related to fluffy balls; see transcript on the next page.

Conventions used in the transcript:

(w) = expression in words	(Sf g) = speech-framed gesture
(g) = gestural expression	text in bold = expression of material knowledge

Table 5. Transcript 'Fluffy balls', Team 4, 00:05:16–00:05:45.

#	Student	Speech and actions	Classifications
1.1	Laney	We could use those, like **non-textile materials**, for instance from **AAAAAAAAAAA** Euroshop or Tiger we can get, get at least such **BBBBBBBBBBBBBB** like I just thought of some, those sea anemones or something like that, **CCCCCCCC** like **fluffy balls**	Naming a material (w) Naming an object (g) Naming an object (Sf g) Naming an object (g) Naming an object (w)
1.2	Cora	**DDDDDDDD** Yes we could.	Naming an object (Sf g)
1.3	Laney	They cost like one euro.	
1.4	Cora	Yeah.	
1.5	Laney	That we could sew them.	
1.6	Cora	Yeah.	
1.7	Laney	That would be so fun.	
1.8	Ruby	What do you mean by **fluffy balls**?	Naming an object (w)
1.9	Laney	**EEEEEEEEEEEEEEEEEEEEE** Those like I can't describe it any better	Naming an object (Sf g)
1.10	Cora	**FFFFFFFFFFFFFF** It's like **plastic** **GGGGGGGG** like **quite soft.**	Sensory-spatial (g) Naming a material (w) Sensory-tactile (g) Sensory-tactile (w)
1.11	Laney	**HHHHHHHHHHHHHHHHHH** Some **spikes coming out.**	Sensory-spatial (g) Sensory-spatial (w)
1.12	Cora	**IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII** There are like **small snags**.	Sensory-spatial (g) Sensory-tactile (w)
1.13	Laney	They come in **pink** and **green** and like that.	2* Sensory-visual (w)
1.14	Ruby	Aaa, like that, yeah right.	

Laney suggested that they could use some non-textile materials (1.1) and began to describe an object, a fluffy ball. First, she lifted her right hand, pressed her fingertips together, and began to quickly open and close her grip, stretching her fingers (AAA): She identified the object by mimicking the signature shape of a fluffy ball—fluffy and round with pointy spikes—and the signature quality, squeezability. She continued with a speech-framed gesture (BBB), a modification of the previous gesture. The grip did not close as tightly as before, and her fingers stretched more. The third time she gestured fluffy balls (CCC), she used both hands: She started with her palms facing each other, forming a round ball shape, and her fingers stretched outward, pointing like spikes, and then moved; the gesture (CCC) and respective words 'fluffy balls' co-occurred. Cora recognised what Laney meant (1.2) and produced a gesture (DDD) that was a simplification of Laney's prior gestures: Cora pressed her fingertips together, opening and closing her grip twice. Ruby, not being on the same page as the others, requested an explanation (1.8). Laney began to explain (1.9): Her gesture (EEE) was nearly identical to her previous one (CCC), only with smaller movements and more repetition. Since the gesture did not really add any new information, Cora stepped in (1.10) and described the balls with the word 'plastic', accompanied by a spatial gesture (FFF) showing the shape of the ball, and the word 'soft', accompanied by a tactile gesture (GGG) showing fluffiness. Laney continued (1.11) with the word 'spikes', accompanied by a spatial gesture (HHH) showing the form and length of the fluffy balls, while Cora (1.12) used the word 'snags', accompanied by a spatial gesture (III) starting with the diminished form of snags and ending with the shape of a ball. Then, Laney continued (1.13) with a description of the usual colours of the fluffy balls, and Ruby (1.14) finally got the idea of fluffy balls.

To summarise the example above, Laney's first gesture (AAA) was simplified and modified several times (to BBB, CCC, DDD, EEE), but the central idea of the signature shape and quality of fluffy balls remained; with repetition, *the gesture became more and more abstract* (cf. Chu & Kita, 2008). As the explanations began to grow in detail, they included more dimensions simultaneously: (1.10) and (1.12) are examples of word-gesture pairs where words and gestures operate in different dimensions (spatial and tactile). The modalities became specialised, and several meanings were communicated simultaneously and efficiently.

In the teams' design conversations, gestures generally conveyed additional information efficiently: the signature qualities of objects; precision (e.g. by showing the exact size, place or object in question); location (e.g. that the strings used for fastening would be tied around *the neck*); time dimension; and movement (e.g. how the light fabric would hover horizontally when a child moved). Such information is *elemental for designing 2D or 3D artefacts.*

The 'behaviour of materials' dimension in detail.

In the word cloud of 'behaviour of material' (Figure 7, on the next page), the volume of longer expressions is eye catching. The amount of the smallest text-type, that is, individual expressions, is higher than that in the 'naming' and 'sensory' clouds, suggesting that many 'behaviour' expressions were used only once during the discussion. The use of negations (e.g. 'not-textile', 'not-washable', 'does-not-stretch') was also greater, but it was hard to determine whether this increase implied a lack of more specific expressions (i.e. narrow vocabulary) or a way to weave the conversation by linking one's turn-at-talk to the previous turns with the (negations of) previously used words. In total, the expressions in this dimension were longer, and often, even if a one-word expression was available, the teams preferred a longer one.

Many of the longest expressions came from Team 1. They also produced more gestures to describe 'behaviours' than did the other teams, and they used more descriptive language—speech and gestures—than did the other teams. Team 2 was at the other extreme: Their conversations on the behaviours of the materials were rather short and 'technical' in nature, focusing mainly on evaluating the looseness and stretchability of the ribs and on how to make sufficiently stiff fins for the shark. The use of different kinds of expressions may reflect, at least partly, the teams' different approaches to an authentic user experience. Team 1 aspired to a strong impression of the sea, waves and shining water, an impression where materials played *more of a mediating role than a representative role*. Again, Team 2 focused on a sea creature, an epaulette shark, and on how to mould and paint leather to create a leather accessory that looked like a real shark—a very practical and 'material' challenge.

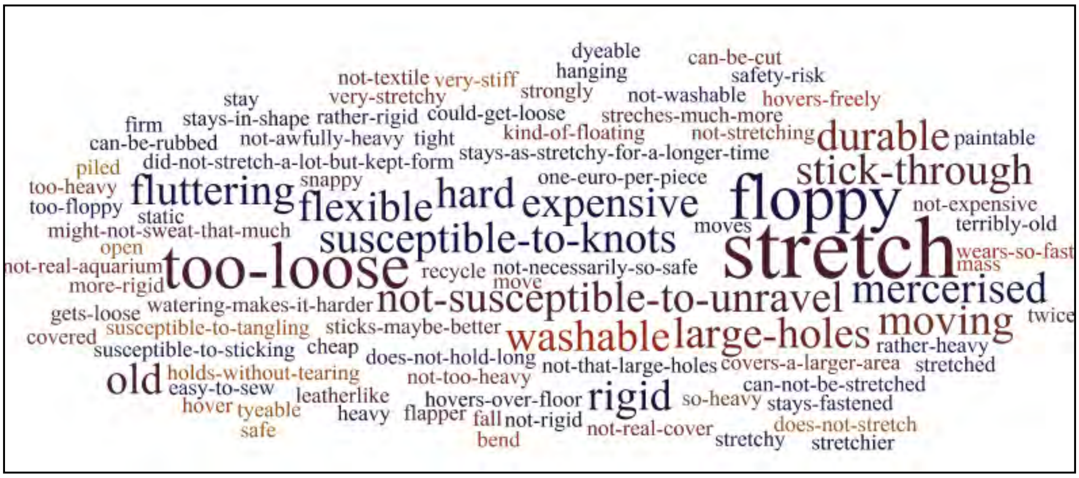


Figure 7. Word cloud visualising shared material knowledge in the 'behaviour of material' dimension.

Building material knowledge during making

The interview data revealed that the teams reported nearly all of the features implemented, which indicates good coverage of the material questions handled during the making phase. While the material knowledge shared during the design conversations emphasised the identification of materials and the role of sensory and behavioural qualities as selection criteria, material decisions and explorations in the making phase highlighted slightly different dimensions. First of all, the objectives of the material decisions and explorations (Table 6) revealed the dimensions of material knowledge with which the teams were struggling in the making phase.

Table 6. Objectives for material decisions and explorations.

Objective of the decision/exploration	**Team 1 (%)**	**Team 2 (%)**	**Team 3 (%)**	**Team 4 (%)**	**Total (%)**
Selecting a material	47	25	48	56	**43**
Practising a technique	26	40	22	28	**29**
Adjusting tools or practising their use	16	15	9	0	**10**
Testing combinations of materials	11	20	21	16	**18**
Totals	**100**	**100**	**100**	**100**	**100**

The reported objectives (Table 6) suggest that the teams focused most of their attention on 'selecting a material'. The second place involved 'practicing a technique', while a fairly small amount of attention was focused on tools (usually a notorious overlock sewing machine) and combinations of materials. *This order reflects the nature not only of the new material knowledge needed but also of the material challenges the teams took upon themselves*: Most ideas focused on creating authenticity with the materials themselves, not heavily processing them. An interesting trend in material selections was that even if all of the teams discussed—whether only briefly or in more detail—non-textile materials, such as 'led strips', 'optical fibre', 'plastic pipes', 'iron wire' and 'Styrofoam balls', none of the materials named were tested or used in the making phase. Only a few solutions outside the world of textiles and beads, such as pipe insulation for creating the 3D form of the shark (Team 2) and soap pads for the octopus' suction cups (Team 3), were tested. The techniques selected were either familiar (e.g. Team 1 with fish netting; Team 2 with crocheting; Team 4 with using a glue-water mixture to stiffen yarn) or taught at the time of the assignment (sewing and sewing with an overlock machine). The one exception was Team 2, with their techniques of leather moulding and painting. In other words, the teams approached material knowledge as a tool to address the challenges of making, not as an end in itself.

The next section presents the results for how the teams built new material knowledge (Table 7). In general, *most decisions were based on material manipulations* instead of on mere sensory perception or working knowledge from previous experiences. One exception to this was Team 1, for whom sensory perception was slightly more inviting than manipulation. On Team 1, as well as on other teams, the decisions based on sensory perception—vision, in practice—concerned the materials used for fillings or materials not considered central to the user experience.

Table 7. How material knowledge was built in the making phase.

	Team 1 (%)	**Team 2 (%)**	**Team 3 (%)**	**Team 4 (%)**	**Total (%)**
Decisions based on…					
… material manipulation	47	85	70	61	**63**
… sensory perception	53	0	26	33	**32**
… working knowledge with no materials at hand	0	15	4	7	**5**
Decision criteria: solution passed because it was…					
…fit for purpose	47	85	66	71	**67**
…easily available and fitting enough	47	5	17	22	**23**
…a compromise due to schedule/budget/skills	6	10	17	7	**10**
Consequences:					
1st proposed solution passed	58	40	57	44	**54**
1st proposed solution failed, but					
… a new solution fulfilled the planned feature	42	60	30	56	**46**
… design premises were reprioritised to find a solution	0	0	13	0	**4**

Usually the solutions were accepted because the ideas were considered fit for purpose. The teams did not, in general, specify in detail the criteria applied during evaluations, which might implicate that at that point—in the making phase—the team members had already internalised the criteria so well that they saw no point in explicating them. Yet, the selection process could be rather pragmatic, especially *when materials were not a key part of the user experience*: The teams often selected materials that were *easily available and fitting enough*. Such pragmatism is understandable considering the tight timeframe under which they were working. On the other hand, they laboriously hunted for key materials across the metropolitan area, from diverse flea markets to the Reuse Centre, and tested key features again and again; the teams possessed ample ambition when it came to pursuing important parts of the aspired-to user experience.

Finally, the consequences of using those rather pragmatic criteria were that either the first proposed solution passed, or if it failed, the teams found another solution to fulfil the planned feature. The process was usually quite straightforward, for example, when Team 2's innovative idea of connecting pieces of pipe insulation with tape failed to support the 3D form of the epaulette shark, so they had to use wool filling instead. Occasionally, coming up with an idea to fulfil design premises was more difficult, as when Team 4 tested several fabrics to create a certain impression of a coral and finally decided to crochet it. Only Team 3 reported having to compromise and reprioritise their premises as a result of their high standards for authenticity (hard beak, curly tentacles that one could bend into various positions, a stretchy material with octopus-like colours), which made the completion of the task unfeasible within the schedule and budget. In the final interview, all of the teams felt satisfied; considering the circumstances, they were happy with what they had accomplished. Even in cases in which the teams had compromised, they still considered the end result to be satisfying. In fact, some considered those solutions even better than the original ones. In general, pragmatism ruled, and the teams all delivered their accessories in time. The final artefacts, wearable sea creatures, appear in Figure 8.

Figure 8. Wearable sea creatures. From left to right: sea star by Team 1; epaulette shark by Team 2; octopus by Team 3; and coral cape by Team 4.

Discussion

Designing and making is a creative knowledge-intensive endeavour. We set out to study novice student teams' material knowledge, assuming that the collaborative setting that the students faced encouraged them to share and make their relevant material knowledge visible and audible in conversations and to reveal it in practical actions of evaluating, selecting and testing materials. That material knowledge then manifested in material decisions and became substantiated in final artefacts—in this case, wearable sea creatures. Therefore, the two viewpoints on material knowledge that we took focused our analyses on collaborative design conversations in video recordings as well as on material decisions and explorations during making.

We found that material knowledge was frequently expressed in conversations, and practically all material aspects of any importance were tested prior to their actual implementation; the student teams used material knowledge as a tool for designing and making, and they took on the challenge of building new local material knowledge seriously. Furthermore, in our results, modalities indeed became specialised: Words contributed mostly to naming and describing visual qualities, while gestures, as expected, played a specific role in expressing spatial qualities related to students' material knowledge, such as information about precision, location, changes and movement within time and space. Thus, our results support Visser's findings (2010) on the role of gestures for designing. Moreover, we found that gestures convey the signature qualities of objects, that is, qualities that we recognise from personal embodied experiences and that make us recognize certain objects as distinct from other similar objects; this finding supports the results by LeBaron and Streeck (2000). In our data, no conventionalised gestures appeared but interpretations had to be based on kinesic features and on the context. However, the gestures conveyed the teams' embodied knowledge of the materials and material qualities smoothly and with considerable expressive power. However, our analysis confirms Visser's finding (2010) that the kinesic features of gestures do not provide sufficient—or even the most relevant—information for categorising gestures, but the neighbouring context, usually speech, was necessary. Whether the decision to use the same classification for expressions in words and gestures aligned with the assumption that modalities become specialised is arguable. To our knowledge, no applicable classification for substantial gestures is available for scrutinising their representational power regarding *designing and the (material) knowledge needed in designing*. By using the classification adapted from Wastiels et al. (2013) as a starting point, we contribute to the discussion on the power of gestures *in and for* designing artefacts, especially as expressions of material qualities and embodied material experiences. The important message we want to emphasise is that *both of the modalities we studied carried important meanings and contributed together to the advancement of the designing*.

Pedgley (2014, p. 340) considered sensorial information as the key to creating a user experience, a finding that the present study confirmed. In this assignment, all teams pursued authenticity, often through visual features. From the perspective of embodied experiences, the fact that the teams often left tactile aspects aside was interesting, possibly because *nobody had embodied a tactile experience with sea creatures*, and getting that experience was unlikely, as the children using those accessories would also have that kind of experience. The reasoning around *tactile* aspects focused not so much on authenticity as on the creation of a pleasant user experience.

According to a review by Karana (2010), design students had difficulty selecting materials during the designing, and they delayed material decisions as far as possible. Indeed, material decisions challenge designers' creativity (Karana, Pedgley, & Rognoli, 2015). Karana (2010) found that design students avoided using new materials or learning about new processing techniques. In the present study, *the number of innovative, non-textile materials mentioned in designing was substantially higher than the number of explored ones*, which implies that the teams had (some level of) knowledge of and interest in new materials, but that interest was lost during the making phase. The techniques selected, on the other hand, were often familiar, and most of the effort to learn new techniques and tools focused on the techniques that the curriculum introduced, that is, sewing and crocheting. At this point, it should be noted that the teams had ample ambition in their pursuits of authenticity and the use of recycled materials. The 3D structures that the teams produced were rather challenging, and to make those structures, they had to create local material knowledge, even if they had resorted to more traditional materials. When "the reality of the making" hit the teams, they reprioritized "the reality of the object" and "the reality of the user" (Bezooyen, 2013, p. 279) to maintain the capacity to fulfil the assignment, a phenomenon visible in the criteria used to make material decisions and explorations, and in the consequences of the failure of the first solution during explorations. Still, in the final interviews, all the teams noted that more time for making would have made a difference, but they did not feel compelled to overly make compromises regarding the user experience due to schedule or budget constraints. To conclude, the teams took on the challenge of authenticity and created demanding 3D structures on a small budget and within a tight timeframe while pragmatically prioritising the number of challenges they took on and the resources available to them.

In this assignment, the students had no access to actual materials prior to the 3D modelling, and they often made their final material decisions during the making phase. Heimdal and Rosenqvist (2012) argued that if the selection of materials is based on qualities defined before the selection process, the materials become *solutions rather than potentials* for innovation. In this case, the support structure guided the process in that direction. In the interviews, the teams all noted that had they had access to actual materials earlier in the design phase, they would not have known what to do with them; the students felt that the supporting structure actually facilitated their process. In the future, it would be interesting to set up a comparative setting in which students familiarise themselves with materials in the early design phases, and then to study the various aspects of material knowledge shared under those circumstances.

Acknowledgements
The present study has been supported by the Academy of Finland (under project no. 265922). We would also like to thank Henna Lahti, the teacher for the Sewing Technology course, and Kaiju Kangas, the teacher for the Knitting and Crocheting course. We thank the students for their participation in the study and for their giving informed consent to publish video still images, photos and working documents. Pirita Seitamaa-Hakkarainen, Henna Lahti, Kaiju Kangas and Tellervo Härkki co-designed the design and make assignment. Tellervo Härkki was responsible for the practical arrangements and video recording of the design sessions as well as the development and implementation of the eDiary data collection method. The final interviews after the making phase were planned and conducted by Tellervo Härkki, who also developed the method of analysing the data. Tellervo Härkki and Pirita Seitamaa-Hakkarainen wrote the present article, together with Kai Hakkarainen. In addition, we are thankful for the children who were brave enough to pose with our animal accessories at Sea Life Helsinki, as well as their parents for giving their full consent to publish the photographs. Furthermore, we wish to thank the University of Helsinki Language Centre for providing proofreading services, IBS video/Mikael Kivelä for the support regarding the video infrastructure, and Inka Laine for finalising the video captures for publishing.

Tellervo Härkki
Doctoral Student
University of Helsinki, Faculty of Behavioural Sciences
Email address: tellervo.harkki@helsinki.fi

Pirita Seitamaa-Hakkarainen
Professor
University of Helsinki, Faculty of Behavioural Sciences
Email address: pirita.seitamaa-hakkarainen@helsinki.fi

Kai Hakkarainen
Professor
University of Helsinki, Faculty of Behavioural Sciences
Email address: kai.hakkarainen@helsinki.fi

References

Alibali, M. W. (2005). Gesture in spatial cognition: Expressing, communicating, and thinking about spatial information. *Spatial Cognition & Computation, 5*(4), 307–331.

Alesina, I., & Lupton, E. (2010). *Exploring Materials: Creative Design for Everyday Objects*. Princeton: Architectural Press.

Ashby, M., & Johnson, K. (2014). *Materials and Design: The Art and Science of Material Selection in Product Design.* Amsterdam: Elsevier.

Baird, D. (2004). *Thing Knowledge: A Philosophy of Scientific Instruments*. Berkeley: University of California Press.

Bekker, M. M., Olson, J. S., & Olson, G. M. (1995). *Analysis of gestures in face-to-face design teams provides guidance for how to use groupware in design*. Proc. DIS95, Conference Designing Interactive Systems: Processes, Practices, Methods, & Techniques, (pp. 157–166). ACM Press.

Bereiter, C., & Scardamalia, M. (2003). Learning to work creatively with knowledge. In E. De Corte, L. Verschaffel, N. Entwistle, & J. van Merriënboer (Eds.), *Powerful learning environments. Unraveling basic components and dimensions* (pp. 55–68). Oxford, UK: Elsevier Science.

Bezooyen, A. (2013). Materials Driven Design. In E. Karana, O. Pedgley, & V. Rognoli (Eds.), *Materials Experience: fundamentals of materials and design* (pp. 277–286). Oxford: Butterworth-Heinemann.

Bohnenberger, S. (2013). *Material exploration and engagement: Strategies for investigating how multifunctional materials can be used as design drivers in architecture* (Unpublished doctoral dissertation). RMIT University. Retrieved from https://researchbank.rmit.edu.au/view/rmit:160564

Chu, M., & Kita, S. (2008). Spontaneous gestures during mental rotation tasks: Insights into the microdevelopment of the motor strategy. *Journal of Experimental Psychology: General, 137*(4), 706–723.

Détienne, F., & Visser, W. (2006). Multimodality and parallelism in design interaction: co-designers' alignment and coalitions. In P. Hassanaly, T. Herrmann, & G. Kunau (Eds.), *Cooperative Systems Design: A Challenge of the Mobility Age* (pp. 118–131). Amsterdam: IOS Press.

Donovan, J., Heinemann, T., Matthews, B., & Buur, J. (2011). Getting the point: The role of gesture in managing intersubjectivity in a design activity. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing, 25*(3), 221–235.

Eris, O., Martelaro, N., & Badke-Schaub, P. (2014). A comparative analysis of multimodal communication during design sketching in co-located and distributed environments. *Design Studies, 35*(6), 559–592.

Gibbs, R. W. (1997). How Language Reflects the Embodied Nature of Creative Cognition. In T. B. Ward, S. M. Smith, & J. Vaid (Eds.), *Creative Thought: An Investigation of Conceptual Structures and Processes* (pp. 351–373). American Psychological Association.

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in Education*. London: Routledge.

Doordan, D. P. (2003). On Materials. *Design Issues, 19*(4), 3–8.

Ekman, P., & Friesen, W. (1969). The repertoire of nonverbal behavior: categories, origins, usage and coding. *Semiotica,* 1, 49–98.

Enfield, N. J. (2009). *The Anatomy of Meaning. Speech, gesture and composite utterances*. Cambridge: Cambridge University Press.

Heimdal, E., & Rosenqvist, T. (2012). Three roles for textiles as tangible working materials in co-design processes. *CoDesign, 8*(2–3), 183–195.

Hennessy, S., & Murphy, P. (1999). The Potential for Collaborative Problem Solving in Design and Technology. *International Journal of Technology and Design Education, 9*(1), 1–36.

Jewitt, C. (2014). An Introduction to Multimodality. In C. Jewitt (Ed.), *The Routledge Handbook of Multimodal Analysis* (pp. 15–30). London: Routledge.

Kangas, K., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2013). Design expert's participation in elementary students' collaborative design process. *International Journal of Technology and Design Education, 23*(2), 161–178.

Karana, E. (2010). How do materials obtain their meanings? *METU JFA, 27*(2), 271–285.

Karana, E., Pedgley, O., & Rognoli, V. (2015). On Materials Experience. *Design Issues, 31*(3), 16–27.

Kendon, A. (2004). *Gesture: Visible action as Utterance*. Cambridge: University Press.

Kress, G. (1993). Against arbirtrariness. *Discourse and Society, 4*(2), 169–191.

Lahti, H., Seitamaa-Hakkarainen, P., Kangas, K., Härkki, T., & Hakkarainen, K. (2016). Textile teacher students' collaborative design process in a design studio setting. *Art, Design and Communication in Higher Education*, *15*(1), 35–54.

Lavergne, J., & Kimura, D. (1987). Hand movement asymmetry during speech: No effect of speaking topic. *Neuropsychologia*, 25, 689–693.

LeBaron, C., & Streeck, J. (2000). Gestures, knowledge, and the world. In D. McNeill (Ed.), *Language and Gesture* (pp. 118–138). Cambridge: Cambridge University Press.

McNeill, D. (1985). So You Think Gestures are Non-Verbal? *Psychological Review, 92*(3), 350–371.

McNeill, D. (1992). *Hand and Mind: What Gestures Reveal about Thought*. Chicago: University of Chicago Press.

McNeill, D. (2006). Gesture and Communication. In K. Brown (Ed.), *The Encyclopedia of Language and Linguistics* (pp. 58–66). New York: Elsevier.

Melinger, A., & Levelt, W. J. M. (2004). Gesture and the communicative intention of the speaker. *Gesture, 4*(2), 119–141.

Murphy, K. M. (2012). Transmodality and temporality in design interactions. *Journal of Pragmatics,* 44, 1966–1981.

Pedgley, O. (2014). Materials selection for product experience: New Thinking, New Tools. In E. Karana, O. Pedgley, & V. Rognoli (Eds.), *Materials Experience: fundamentals of materials and design* (pp. 337–349). Amsterdam: Butterworth-Heinemann.

Ramduny-Ellis, D., Dix, A., Evans, M., Hare, J., & Gill, S. (2010). Physicality in Design: An Exploration. *The Design Journal, 13(*1), 46–76.

Streeck, J., & Kallmeyer, W. (2001). Interaction by inscription. *Journal of Pragmatics, 33*(4), 465–490.

Tang, J. C. (1991). Findings from observational studies of collaborative work. *International Journal of Man–Machine Studies,* 34, 143–160.

Visser, W. (2010). Function and form of gestures in a collaborative design meeting. In S. Kopp & I. Wachsmuth (Eds.), *Gesture in Embodied Communication and Human-Computer Interaction*, *GW 2009* (pp. 61–72). Heidelberg: Springer.

Wastiels, L., Schifferstein, H. N. J., Wouters, I., & Heylighen, A. (2013). Touching Materials Visually. *International Journal of Design, 7*(2), 31–41.

Wundt, W. (1973). *The language of gestures*. Hague: Mouton.